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ASD TR 7-556 (XXIII)

ASD INTERIM REPORT 7-556 (XXIII)
1 DECEMBER 1962 TO 1 MARCH 1963

IMPROVED METHODS FOR THE PRODUCTION OF TITANIUM ALLOY EXTRUSIONS

MURRAY H. LEVINE

REPUBLIC AVIATION CORPORATION
MANUFACTURING RESEARCH

CONTRACT: AF 33(600)34098
ASD PROJECT: 7-556

INTERIM TECHNICAL ENGINEERING REPORT
1 DECEMBER 1962 TO 1 MARCH 1963

A three section tungsten carbide draw die was modified to permit drawing of tee shapes without restraining of the edges. Two tee shapes, each of Ti-7Al-4Mo and Ti-4Al-3Mo-1V alloys were successfully drawn through the required final pass of 0.043 inch.

BASIC INDUSTRY BRANCH
MANUFACTURING TECHNOLOGY LABORATORY

AERONAUTICAL SYSTEMS DIVISION (AFSC)
UNITED STATES AIR FORCE
WRIGHT-PATTERSON AIR FORCE BASE, (OHIO)

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ASD TR-7-556 (XXIII)

ASD INTERIM REPORT 7-556 (XXIII)
March 1963

IMPROVED METHODS FOR THE PRODUCTION OF TITANIUM ALLOY EXTRUSIONS

Murray H. Levine

Republic Aviation Corporation
Contract: AF33(600)-34098
ASD Project 7-556

Interim Technical Engineering Report
1 December 1962 - 1 March 1963

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REPUBLIC AVIATION CORPORATION

ABSTRACT-SUMMARY
23rd Interim Technical Progress Report

ASD INTERIM REPORT 7-556 (XXIII)
March 1963

IMPROVED METHODS FOR THE PRODUCTION OF TITANIUM ALLOY EXTRUSIONS

Manufacturing Research Department
Republic Aviation Corporation

A three section tungsten carbide draw die was modified to permit drawing of tee shapes without restraining of the edges. Two tee shapes each of Ti-7Al-4Mo and Ti-4Al-3Mo-1V alloys were successfully drawn through the required final pass of 0.043 inch.

Seventeen dies for the Part V, B-70 shape extrusion program have been machined at the Babcock & Wilcox Company. Seven dies are of the North American Aviation design E-64-12 having a 1/16" cross section tee configuration. Seven dies are of the North American Aviation design E-64-15 having a 3/32" cross section tee shape, and three dies are of the E-64-15 design having two tee ports for a multihole extrusion. The above designs have been slightly modified to be compatible with existing warm draw tooling.

NOTICE

The work reported in this document has been made possible through the support and sponsorship extended by the Air Materiel Command under Contract No. AF33(600)-34098. It is published for technical information only and does not necessarily represent recommendations or conclusions of the sponsoring agency.

REPUBLIC AVIATION CORPORATION

FOREWORD

This Interim Technical Progress Report covers the work performed under Contract AF33(600)-34098 from 1 December 1962 to 1 March 1963. It is published for technical information only and does not necessarily represent the recommendations, conclusions or approval of the Air Force.

This Contract with Republic Aviation Corporation, Farmingdale, Long Island, New York, was initiated under the Aeronautical Systems Division Project 7-556, "Improved Methods for the Production of Titanium Alloy Extrusions." It is administered under the direction of Mr. T.S. Felker of the Basic Industry Branch (ASRCTB), Manufacturing Technology Laboratory, Aeronautical Systems Division, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio.

Mr. M.H. Levine of the Manufacturing Research Department, Republic Aviation Corporation, was the engineer in charge. Others who cooperated in the research and in the preparation of the report were: G. Pfanner, Senior Manufacturing Research Group Engineer; E. Bohanek, Titanium Metals Corporation of America and T. Rice, Allegheny Ludlum Steel Corporation.

The primary objective of the Air Force Manufacturing Methods Program is to increase producibility and improve the quality and efficiency of fabrication of aircraft, missiles and components thereof. This report is being disseminated in order that methods and/or equipment developed may be used throughout industry, thereby reducing costs and giving "MORE AIR FORCE PER DOLLAR."

Your comments are solicited on the potential utilization of the information contained herein as applied to your present or future production programs. Suggestions concerning additional manufacturing methods development required on this or other subjects will be appreciated.

Written by: M.H. Levine
M.H. Levine
Principal Mfg. Rsch. Engineer

PUBLICATION REVIEW

Approved by: Robert W. Hussa
Robert W. Hussa, Assistant Chief
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Approved by: T.F. Imholz
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Manufacturing Research Engineer

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HISTORY OF THE PROGRAM

"Improved Methods for the Production of Titanium Alloy Extrusions" is sponsored by the Air Materiel Command under Contract No. AF33(600)-34098. The development program was originally scheduled in five parts to produce titanium alloy structural shapes in three size categories. The extrusion development for the first and second category shapes (Figures 1 and 2) has been completed in Parts II and III of the program. The double tee shape (Figure 3) originally selected for extrusion development in Part IV, has been replaced with thinner tee shapes (Figure 4) to be produced by a combination of extrusion and subsequent drawing. Such thinner shapes represent current design requirements in advanced airframe structures. The scope of the program was further increased by the addition of Parts V to produce a typical B-70 titanium alloy shape and Part VI to develop heat treatment procedures for full length titanium alloy extrusions. Part VI was subsequently deleted. The program parts are listed below as originally scheduled and as revised.

	Original Program		Revised Program
Complete	<u>Part I</u> Determination of Shapes and Materials <u>Part II</u> Extrusion of First Category Shapes (Fig. 1) <u>Part III</u> Extrusion of Second Category Shapes (Fig. 2)		
Deleted	<u>Part IV</u> Extrusion of Third Category Shape (Fig. 3) <u>Part V</u> Final Report		<u>Part IV</u> Extrusion and Drawing of Third Category Shapes (Figure 4) <u>Part V</u> Extrusion and Drawing of Typical B-70 Shape
		Deleted 12 Oct. 1962	<u>Part VI</u> Heat Treatment Development

Part I

The survey of airframe producers was concluded in Part I and resulted in the selection of typical extrusion shapes desired in titanium alloys for airframe design. These shapes are illustrated in Figures 1, 2 and 3. The survey also determined the test properties required of titanium alloy extrusions for high temperature service. The major titanium producers and research laboratories were consulted for information and recommendations for the choice of alloys most closely conforming to the property requirements.

Part II

The alloys which were selected for extrusion in Part II are listed below:

C-135 AMo	7.0% Al. 4.0% Mo.
MS-821	8% Al. 2% Cb. 1% Ta.
Ti-155A	5% Al. 1.4% Fe. 1.5% Cr. 1.2% Mo.

The extruders who participated in the Part II extrusion development are:

The Babcock and Wilcox Company
The United States Steel Corporation
The H. M. Harper Company

The sections and alloys which were extruded in Part II by these extruders are:

Company	Billet Dia.	Section	Alloys
Babcock & Wilcox	4"	Angle	C135 AMo and MS 821
U. S. Steel	2-3/4"	Channel	Ti 155A and C135 AMo
H. M. Harper	3-7/8"	Zee	MS 821 and Ti-155A

The extrusion development of the Part II section is described in detail in Quarterly Report Nos. 3, 4 and 5. The dimensional objectives established in Part I were approached but were not fully realized during the Part II extrusion development. Various lubricants, die materials and extrusion techniques were investigated and the best results were obtained with hot work tungsten steels and glass lubrication techniques.

The straightening trials which were conducted with the channel and angle extrusions produced in Part II are described in Quarterly Reports 5, 6 and 7. Report No. 7 also contains a dimensional evaluation of the straightened lengths which indicates that the extrusions approached but did not realize the straightness and twist specifications for aluminum extrusions of similar cross section.

Part III

The Part III development of extrusion techniques for the tee and hat shapes (Figure 2) was conducted by Babcock and Wilcox and by Compagnie due Filage des Metaux et des Joints Curty (Cefilac), the French company that developed the glass lubrication technique for steel extrusion. The Part III extrusion trials are described in Reports 8, 9, 10, 12, 13 and 14. The most successful Cefilac trials are described in Report 12 and the most successful Babcock and Wilcox trials are described in Reports 9 and 14. Similar results in reasonable dimensional uniformity with good surface finish in 15-25 foot lengths were obtained by both extruders. Effective glass lubrication held die wear to a negligible degree and permitted reuse of the dies. Pickup scoring lines in the extruded surface due to titanium pickup upon the extrusion die were present to a degree varying from negligible to appreciable severity. This condition was finally avoided in the last Part III trials at B & W apparently due to clean billet heating and handling practice in which stainless steel billet heating cans and a 900°F chromium plated extrusion liner were used. See Report No. 14. Practically all extrusions produced in Part III were extruded by the full flow lubrication technique in which the billet skin elongates in passing through the extrusion die and separates into discreet particles in the extruded surface. These particles are not in themselves undesirable when small and well divided but are the nucleus for surface depression adjacent to the marks. In addition, when the billet skin contamination in heating is appreciable, the particles produce die abrasion. A study of contamination depth as dependent upon heating time and protective glass coating is still in progress in an effort to determine if the present extrusion process can be improved with better heating practice.

A representative evaluation of the Part III tee extrusions is presented in Reports 13 and 15. The best extrusions are within the dimensional straightness and twist tolerance of aircraft specifications for aluminum extrusions of similar size and shape. However, there is a sufficient range of variation to indicate that a subsequent sizing operation such as "warm" drawing would be advantageous. Further, the current interest in titanium extrusions lies in thinner shapes with smaller tolerances than permitted in aluminum extrusions. As a consequence, the program has been amended as previously described to produce such shapes by means of extrusion and subsequent drawing.

A heat treatment procedure that will consistently produce the objective of 180,000 psi ultimate strength with 8% elongation has not been determined. In many cases, tensile results have been erratic after heat treatment. For earlier mechanical property test results and heat treatment studies, see Reports 4, 5, 6 and 7. A study of heat treatment parameters conducted by Crucible Steel with channel and angle extrusions in 7Al 4Mo alloy is included in Report No. 8. Results with recommended heat treatments and modified treatments are described in Reports 9, 10 and 11. In the latter report, as-extruded material consistently tested 170,000 UTS, 150 YTS and 8% elongation. After heat treatment, results were typically 185 UTS, 175 YTS with 2.5% elongation.

Straightening trials conducted with the Part III tee extrusions at B&W are described in Reports 9, 13, 15 & 17. The last two reports contain an evaluation of the dimensional uniformity and mechanical properties of the straightened Part III tee extrusions produced by B&W in terms of straightening temperatures and modification of jaw assembly.

Part IV

In a previous quarter, a Part IV extrusion and straightening trial was held at Babcock and Wilcox. The purpose of this trial was to establish the reproducibility of the process developed under the Part III extrusion of tee shapes, determine the best lubrication practice, and to extrude an .092" thick tee shaped section based upon the best techniques developed under the 1/8" thick tee shape reproducibility phase. The procedures and results of this trial are discussed in Report No. 17.

Glass contamination studies were conducted at Republic Aviation Structures Laboratory and at the Babcock and Wilcox Production and Process Laboratory facilities to determine the influence of billet heating times and glass composition on contamination of titanium extrusions (Report No. 18). For previous studies related to surface contamination, see Reports 10, 12, 14 and 17. The influence of reduced billet heating times on extrusion pressures is discussed in Report No. 19.

Extrusion techniques and results of the extrusion trials (Group No. 17) in which 20-foot lengths of .092" and .062" tee shaped sections were successfully extruded using alumina coated die material, are discussed in Quarterly Report No. 19. The extrusion pressures required were comparable to pressure experienced with the smaller ratio .125" extrusions. Use of alumina coating on the die material prevented die wear, wash and hot deformation of the die. Uniform cross section dimensions from front to back along the extrusion length can be realized using the alumina coated dies.

A combination of hot stretch and punch straightening of the Group 17 extrusions produced the straightest extrusion lengths to date. The various extrusion techniques which influence the cross section dimensions of the as-extruded length, and subsequently affect the resistance heating stretch-straightening and detwisting procedure, are discussed in Report No. XX.

High frequency induction heat equipment, coils and accessory equipment have been installed at the Allegheny Ludlum Steel Corporation draw bench facility and are described in Report No. 18. The temperature sensing devices and controllers, induction coil and stress loading cells were calibrated. A four-foot tee section was reduced from a nominal .130" to a uniform .118" cross section in one pass. The procedure and results are discussed in Report No. 19. Ten foot lengths of as-extruded and straightened .125" tee shapes were successfully reduced in one reduction pass to a uniform .110" thickness. The problems encountered and recommended solutions for maintaining constant temperature control of the induction coil, cracking of carbide draw dies, and choice of compatible lubricant are discussed in Report XX and XXI.

The final series of Part IV extrusion trials were conducted at Babcock and Wilcox Company completing the extrusion portion of Part IV. Tee sections, ranging from 20 to 30-foot lengths of 1/16" cross section, were successfully extruded in 7Al-4Mo, 6Al-4V and 4Al-3Mo 1V titanium alloys using alumina coated dies and a combination glass wool-granular glass die pad lubricant. The extrusion procedures and results are discussed in Interim Technical Report XXI.

In the last quarter, a fourth series of extrusion trials were conducted at Battelle Memorial Institute to determine the optimum glass wool composition for the die lubricant system at 1800°F. The glass compositions were melted and blown to fiber form at Battelle Memorial Institute. The results of this trial series are described in Report No. XXII.

The Part IV warm drawing phase was continued during the last quarter. The tee sections were heated in the resistance heated muffle furnace which was installed in October. Twenty-seven as-extruded 20 feet long nominal 1/16" cross section tee shapes consisting of 7Al-4Mo, 6Al-4V and 4Al-3Mo-lV titanium alloys were sized through a .065" draw die. Eight sized .065 shapes were drawn to .058" cross section. Two of the .058" cross section tees were further drawn to .052" cross section.

During this quarter, seventeen extrusion dies representing B-70 shapes are in the process of being machined and cast at the Babcock & Wilcox Company. Fourteen machined dies represent the NAA E64-12 and NAA E64-15 configuration (modified to our existing tooling). Three dies will be cast to a multihole tee configuration having two tee shaped ports. The die dimensions are described herein.

Warm drawing of four tee sections to a final .043" cross section thickness was accomplished during this quarter, using the reworked tungsten carbide draw dies. The modified die configuration and drawing procedure are described in this report.

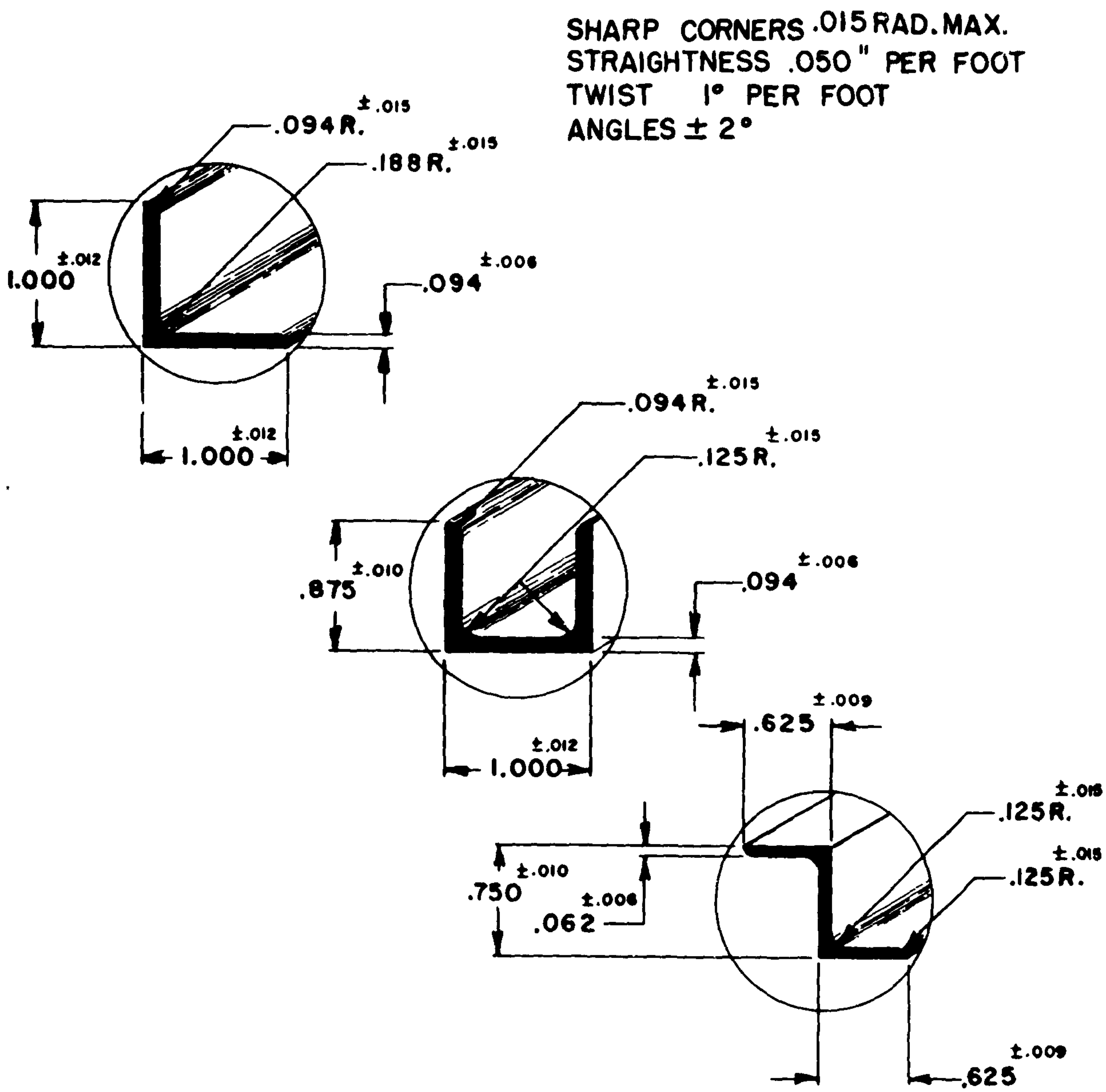


FIGURE I
SHAPES SELECTED FOR EXTRUSION
METHOD DEVELOPMENT
PART II
AF 33 (600) 34098

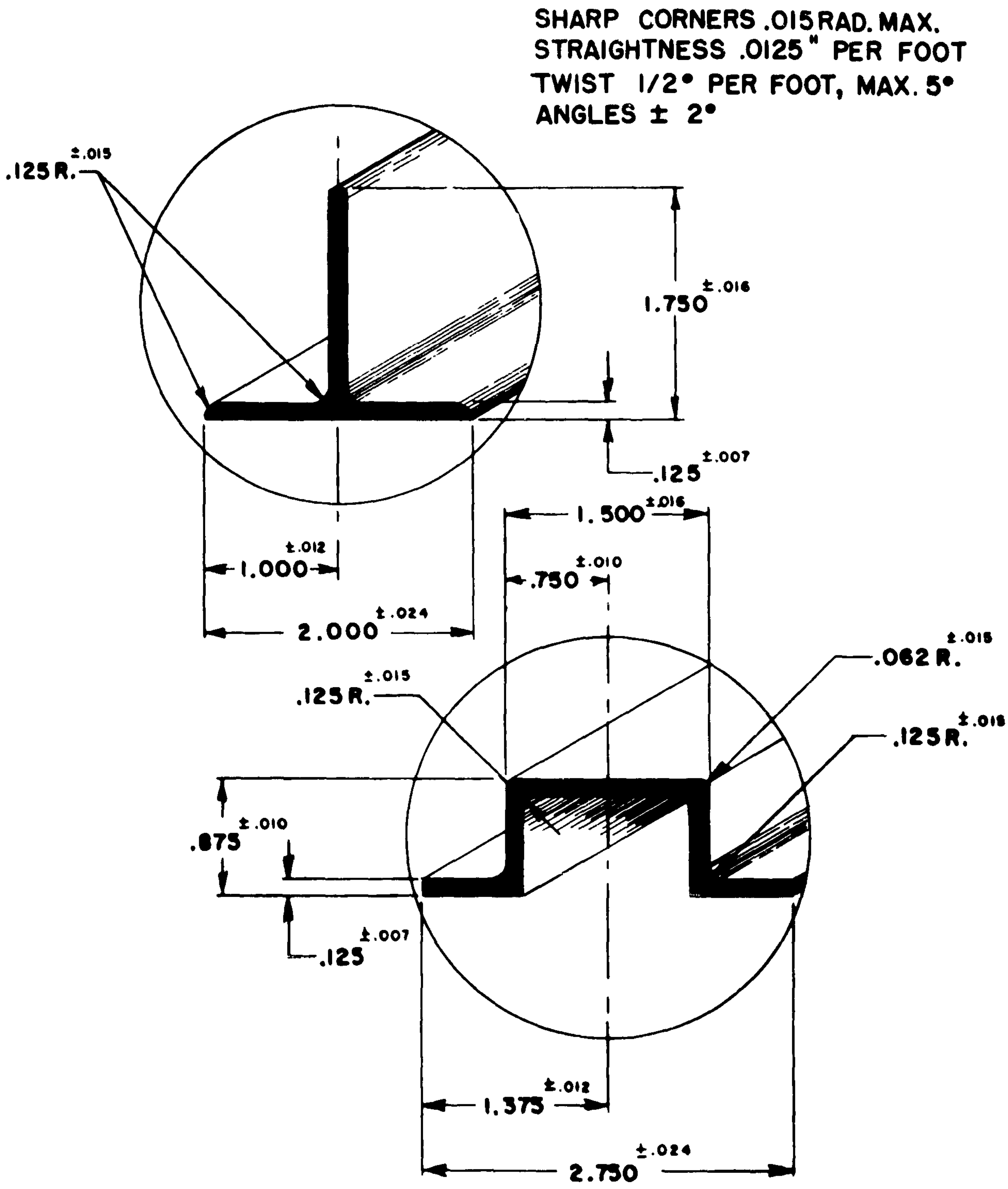


FIGURE 2.
SHAPES SELECTED FOR EXTRUSION
METHOD DEVELOPMENT
PART III
AF 33 (600) 34098

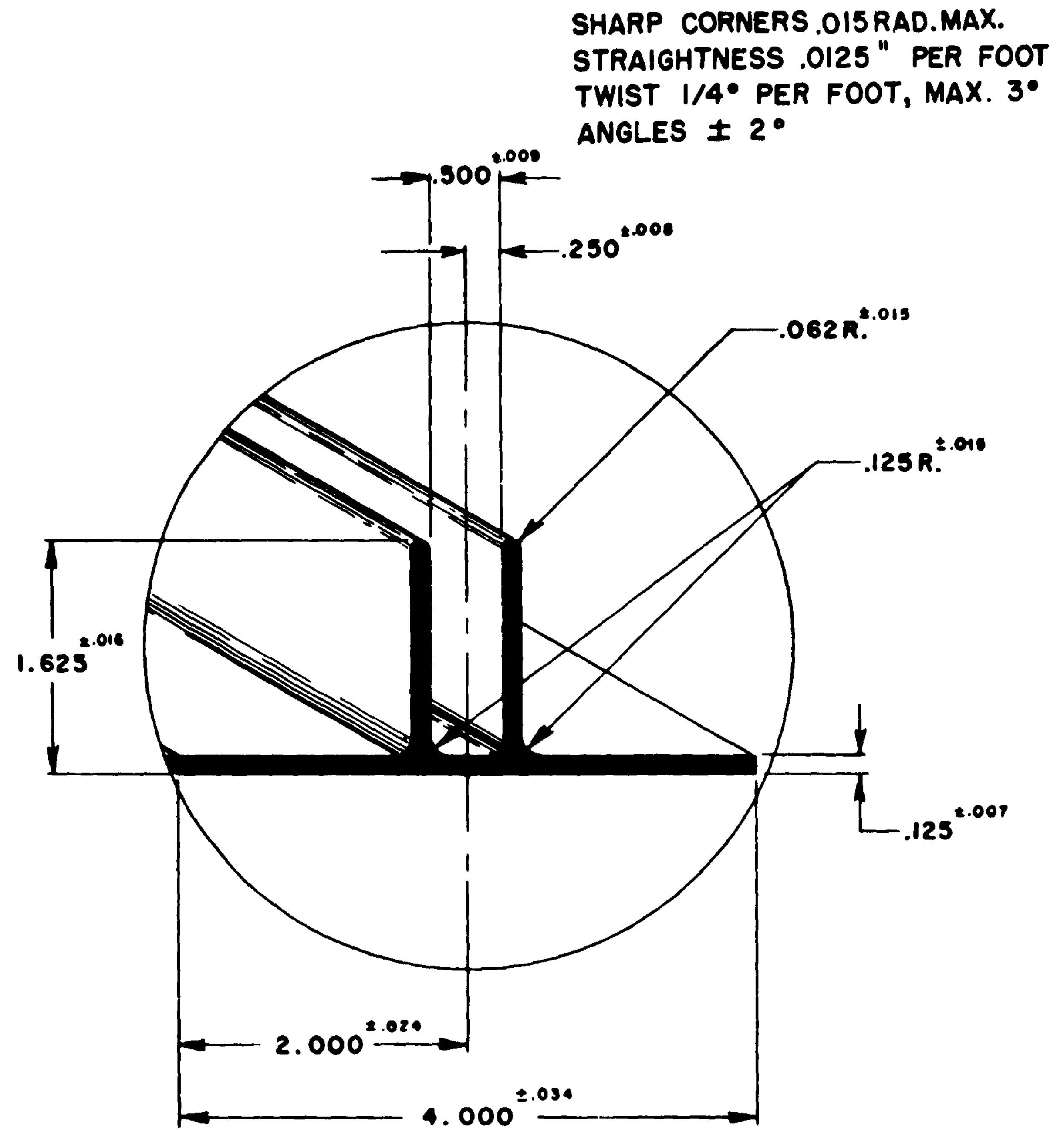
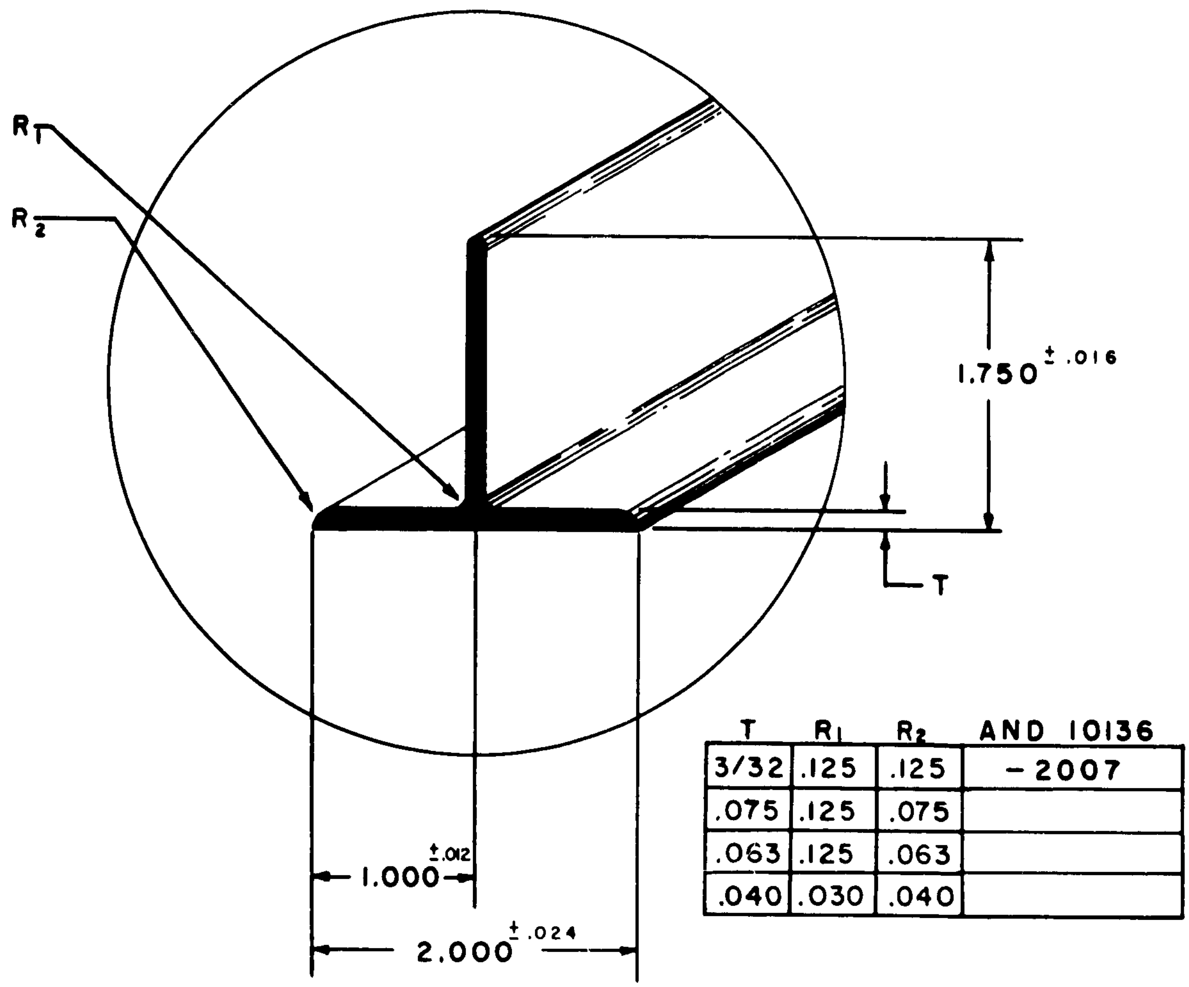


FIGURE 3
SHAPE ORIGINALLY SELECTED FOR PART IV
EXTRUSION METHOD DEVELOPMENT AF 33 (600) 34098

THIS SHAPE HAS BEEN REPLACED BY THE
THINNER TEE SHAPES SHOWN IN FIGURE 4

SHARP CORNERS .005 RAD. MAX.
STRAIGHTNESS 0.0063" PER FOOT
TWIST 1/4° PER FOOT, MAX. 2 1/2°
ANGLES ±1°



T	R1	R2	AND 10136
3/32	.125	.125	-2007
.075	.125	.075	
.063	.125	.063	
.040	.030	.040	

FIGURE 4

SHAPE SELECTED FOR EXTRUSION
METHOD DEVELOPMENT
PART IV
AF 33 (600) 34098

PREPARATION FOR B-70 TEE SHAPE EXTRUSION AND WARM DRAWING TRIALS

Introduction

During the past quarter, preparations for the Part V extrusion effort to extrude B-70 type tee shapes were conducted at the Babcock & Wilcox Company. In view of the past successful achievements in Parts III and IV of this Contract in extruding various titanium alloys and tee section thickness and the knowledge acquired by the extrusion Vendor, it was desirable to select the same Vendor for the Part V program.

Extrusion of B-70 Shaped Tee Sections

The program is being conducted at the Babcock & Wilcox Company, Beaver Falls, Pa. extrusion facilities. The overall objective of this program will be to refine extrusion techniques (developed in Part IV) leading to a production method for extruding tee shaped sections for the XB-70 aircraft. (See Interim Engineering Report No. XXII.)

Two North American Aviation tee shape configurations were selected for this trial effort for the following reasons:

a) Extrusion and drawing of .125" through .062" cross section tee shapes are a present capability and refinement of this process is justified.

b) Tee shaped configurations are desirable since existing tungsten carbide dies and tooling are available from Part IV. (the tee shapes selected have been modified to fit the existing tooling)

c) North American will accept any non-machined extrusion that will be applicable to the B-70 aircraft. Since there are over 300 extruded parts, any minor modification in extruded configuration will be acceptable for North American Aviation testing and evaluation program.

The alloy selected by North American Aviation for this program is the Ti-6Al-4V alloy. This alloy is currently being used because of its consistant properties and weldability. The chemical composition of the 4" round forged stock is as follows: C-.025; Fe-·19; N_2 -015; Al-6.3; Va-4.2; H_2 -.005; O_2-18.

The final cross section thickness after warm drawing of the two selected shapes will conform to N.A.A. shapes E64-12 and E64-15. The as-extruded dimensions are shown in Figures 5A & B.

Facilities and Extrusion Practice

The extrusion press is a 2500-ton Loewy hydropress with pressure accumulators capable of operating the press at the fast extrusion speeds common in steel and titanium extrusion.

The extrusion press is equipped with a 4 3/16" I.D. container and a 4 1/16" hardened steel stem for extruding 4" diameter billets. The 180,000 psi stress limitation in the steel stem required that the press extrusion force be limited to 1080 tons.

The billet surfaces are centerless ground, degreased, heated to 300°F and sprayed with glass slurry prior to heating. The billets are then placed into a pre-heated (1800°F) stainless steel can, covered and given a 60 second argon purge. The can is then placed into a controlled argon atmosphere, electric resistance furnace. During billet heating, the glass slurry formed a protective film of glass over the billet. In subsequent extrusion, the glass film on the billet surface insulates the hot (1800°F) billet from the relatively cooler container liner (800°F).

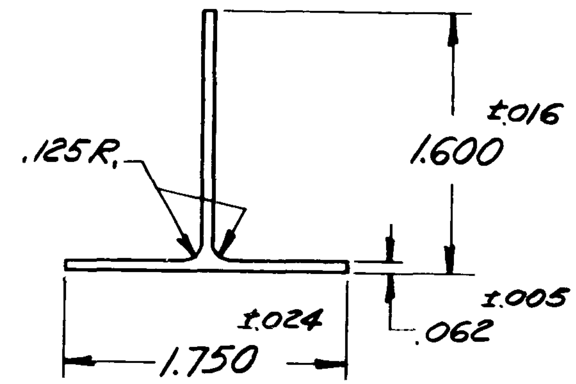
The billets are transferred to the extrusion press with the two-man carrying device illustrated in Report No. 13. The single can method was used and the billet was tipped out of the transport can onto the runout table where additional glass powder is applied.

After the billet is in position in the container, the stem is advanced rapidly until contact is made with the billet. The stem remains in this position for one or two seconds while upsetting the billet, and then extrusion proceeds in about two seconds.

The die is lubricated and protected from washout during extrusion by a film of glass which is continuously fused from a pad of compacted glass powder, glass wool or a composite glass powder and wool which is placed between the die and billet.

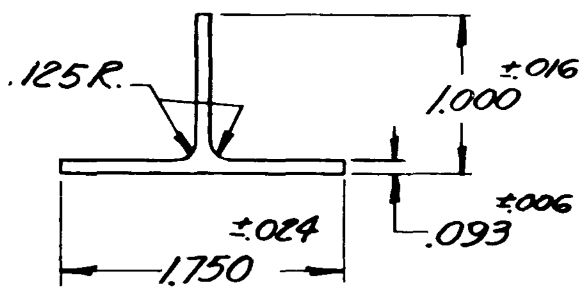
Tungsten steel dies have given the best results (least wear or die deformation) in previous trials and are considered a satisfactory die material for extrusion of the 1/8" x 2" tees. For thinner cross-section extrusions, ceramic coated dies will be evaluated.

For this trial, fourteen Peerless A Tungsten Steel dies were machined to the three-piece design to facilitate application of ceramic coating by the flame spray method. Three multi hole dies will be cast with 2 Tee shaped orifices as shown in Figure 5C.



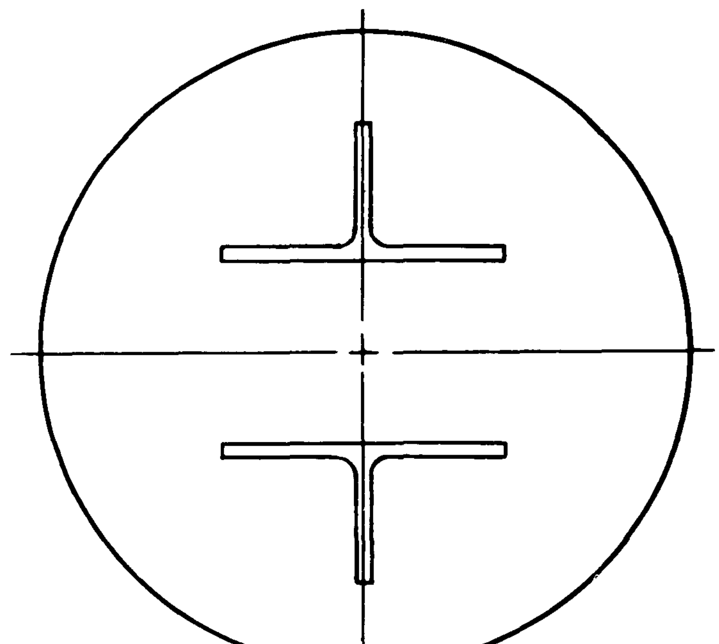
A

Modified NAA E64-12 shape. Seven 3 section dies machined to .082" orifice to allow for .010" alumina coating per side.



B

Modified NAA Shape E64-15. Seven single port 3 piece dies machined to .113" orifice to allow for .010" alumina coating per side.



C

Design of Multihole tee shaped dies(these dies will not be alumina spray coated).

FOURTEEN P.A. TUNGSTEN STEEL DIES WERE MACHINED TO THE THREE-SECTION DESIGN. THE RESULTANT EXTRUDED TEE SHAPED DIMENSIONS ARE SHOWN IN A AND B. THESE SECTIONS WILL BE DRAWN TO .043 AND .080 IN CROSS SECTION RESPECTIVELY. THREE DIES WILL BE CAST WITH TWO TEE SHAPED ORIFICES FOR A MULTIHOLE EXTRUSION TRIAL. THE TEE POSITIONS ARE SHOWN IN C.

FIGURE 5

Extrusion Variables to be Investigated

Satisfactory performance under this program is defined as the complete development of the optimum manufacturing process for the production of extruded tee shapes, to prove that the process is under control. Approximately seventeen billets will be extruded to tolerances in accordance with North American Aviation specifications LB0170-112 and LB0170-122.

Schedule of Extrusion Trials

Based upon previous successful experiences in extruding the thin section Ti-6Al-4V alloy, the extrusion technique and glass lubricants described in Interim Report XXI will be used for this extrusion schedule. A total of seventeen extrusion pushes consisting of ten 3/32" and seven 1/16" cross section tees will be extruded using the E-71 glass series. Of the former tee sections, three 3/32 inch dies have the multihole configuration (2 tee ports per die) resulting in a total of 13, 3/32" tee sections. All sections will be warm drawn as described in the following section.

Warm Drawing Program

Objectives

The objective of this phase is to develop the warm drawing operation leading to the production of close tolerance extruded shapes required for the XB-70 aircraft Satisfactory performance under this phase is defined as the complete warm drawing development of an optimum economic manufacturing process for the production of extrusions to prove the process is under control. The program will be conducted at the newly installed warm drawing facilities at Titanium Metals Corporation of America, Toronto, Ohio.

Variables to be Evaluated

The effort under this program will include, but not be limited to analysis of all variables which affect the process quality and economics such as:

1. Die temperature
2. Number of passes through die
3. Dimensional reduction through each pass
4. Speed of each draw operation
5. Thermal treatment between passes
6. Design of draw dies
7. Die life
8. Die cost
9. Lubricants employed
10. Force required to draw

Drawing Schedule and Requirements

Schedule

Modified N.A.A. Shape: 64E12

Seven tee sections having a nominal cross section of 1/16" will be successively warm drawn through five reductions to a .043 inch cross section.

Shape:64E15

Thirteen nominal 3/32 inch tee shaped sections will be sized through a .092 inch die and drawn through an .087 and .080 die pass to a uniform cross section thickness

Requirements

Each drawn section will be evaluated in terms of the following requirements:

a) minimum length of 20'
b) thickness of flange and section within tolerances described on selected North American drawing 64E12 and 64E15.
c) surface finish 50RMS or better
d) straightness, flatness, angularity, twist radii tolerance and finish surface shall conform to the requirements described in class 1. Finished shapes under North American material specification LB0170-112.

A testing program will be conducted during the drawing program to establish the effects of the drawing parameters on material properties. Final evaluation of the mechanical properties both warm drawn and heat treated will be conducted on representative specimens. Full length evaluation of the extruded tee sections will be conducted with the cooperation of North American Aviation Corporation.

REPORT OF WARM DRAWING TRIALS AT THE ALLEGHENY LUDLUM STEEL CORPORATION

Introduction

The warm drawing portion of Part IV development is being conducted by the Titanium Metals Corporation of America. Earlier experimental work conducted by Titanium Metals in 1959 and 1961 on Allegheny Ludlum Steel Corporation facilities has demonstrated that 5/16" tee sections of titanium-base alloy Ti-6Al-4V could be successfully warm drawn with improvements in dimensional integrity and surface roughness. The procedures basically require refinement in heating, pointing and gripping techniques. Only limited reductions with a maximum total reduction in area of 18% were attempted.

The present four-phase program is concerned primarily with 1/8" thick T-shapes of Ti-7Al-4Mo being warm drawn to thinner sections. These alloy extrusions produced for Republic Aviation Corporation by Babcock and Wilcox and CEFILAC are to be warm drawn at the Allegheny Ludlum Steel Corporation Watervliet facilities to eventual thicknesses of .040".

The proposed program was based on the adoption and usage of continuous induction heating, the use of potentially versatile and economical split carbide dies, and the use of lubricant systems suitable for the warm processing of titanium-base alloys.

The four* phases of this program are generalized as follows:

Phase I — Development of the drawing techniques for sizing as-extruded tee shapes having a cross section of 0.125".

Phase II — The development of drawing techniques for the production of tee shapes having a 0.063" cross section from extrusions of 0.125" section.

Phase III — The development of sizing procedures for extrusions having a cross section of 0.075". This has been modified to start with nominal 0.095" thick extrusions.

Phase IV — The development of drawing procedures to make 0.040" section shapes from tee extrusions having an initial thickness of 0.063".

During the first quarter, all incoming extrusions were inspected for size and surface quality. One dozen, four-foot lengths of CEFILAC extrusions were chemically pointed and annealed and coated for warm drawing trials. The split carbide dies were ordered from American Carbide Company, the 100 KW Lepel unit was authorized for shipment to ALSCO, Watervliet, along with the induction coil. In addition, the effects of various annealing practices on room temperature and elevated temperature (750, 1000, 1250°F) tensile properties were ascertained.

* These phases are subsections to the Part IV warm drawing phase described in the History Section of the report.

During the second quarter, the 100 KW unit was installed and calibrated. Phase I warm drawing trials of Ti-7Al-4Mo extrusions were initiated but with little success due to improper heater coil design and failures due to arcing through the Fiberfrax liner. The arcing was eliminated by the use of preheated cooling water. The 100 KW generator and coil basically became operative and available for heating and drawing evaluations at the start of the third quarter.

In the third quarter, it was demonstrated that temperature control no better than + 100° F would be achieved using the temperature controllers incorporated by the heater manufacturer; however, by heating under constant power input, the temperature variability could be reduced to a nearly acceptable ± 50° F, but at the expense of temperature and draw speed selection.

Utilizing a chemical conversion coat-line-MoS lubricant system, warm drawing with 10/15 percent reduction in thickness of Ti-7Al-4Mo "T" shapes was achieved at temperatures of 750/900° F.

Cracking of the bottom block of the split carbide die assembly was encountered. Remedial measures in terms of reduced tolerance between the mating surfaces of the die backup block eliminated this condition.

In the fourth quarter, drawing of the original Phase I was completed with ten as-extruded . 125" cross section tee shapes, warm drawn through two die cycles to a uniform 0. 100" cross section. Final straightening of these extrusions was performed by the Babcock & Wilcox Co. Shape Finishing Department.

The Phase II effort includes drawing four . 125" tee shapes through three passes to a . 080" cross section.

Sizing techniques to . 090" thickness for the Phase III 3/32" as-extruded tee section were conducted in a one-pass cycle. A second draw pass reduced these extrusions to a . 080" cross section thickness. This phase has been curtailed.

The suitability of the split carbide die assembly for warm drawing titanium tee shapes was demonstrated. The feasibility of induction heating shapes drawn to . 080" thickness under constant power input with good temperature selectivity from 750 to 1400° F was indicated. Below 080" thickness, the induction heating unit was ineffective.

The greatest effort during this quarter was concentrated on the construction of a resistance heated muffle furnace and the reduction of . 063" as-extruded tee sections to a . 040" cross section in 7Al-4Mo, 6Al-4V and 4Al-3Mo-1V titanium alloys (Phase IV). A total of twenty-four 20 foot long tee extrusions have been warm sized through the . 065" die. Eight of the . 065" sections were reduced to . 058" cross section, and two sections were further reduced to . 052" thickness.

In the fifth quarter, the tungsten carbide draw dies were modified in terms of extending the flange and stem opening. Four extrusions originally 3/32" thick were drawn down to 1/16", completing modified Phase III. It was demonstrated that a 27% reduction could be attained in one pass (0.110" to 0.080") with the modified dies when the edges of the extrusion were unrestrained. Previously only nominal 10% thickness reductions were attempted.

Gag straightening was disbanded as being unsuitable for these thin sections, and the resistance heater unit was adopted as a stretcher straightener. Adequate pointing techniques were developed in which only oversize billets were machined, and then the balance of the pointing was conducted by Chem-milling in a nitric-hydrofluorine acid bath.

Equipment problems continued to plague progress. It was found that the 100 KW Lepel induction heater could not heat 1/16" and thinner sections to warm draw temperatures of 1000°F without major costly modifications. A series of heating trials have been unsuccessfully attempted to improve the heating efficiency of the induction heating unit on thin "T" sections in terms of increased coil turns and by insertion in parallel of a bank of ten .01 uf capacitors into the high frequency circuit. In addition, the gripper head could not hold these cold points and continued slippage occurred along with jaw tooth deterioration and O-ring damage. The work was halted pending a decision from TMCA to use their newly installed warm draw facilities for the remainder of the program.

Progress in Development of Warm Drawing Equipment

Heating Equipment

Replacement of the 100 KW Lepel high frequency induction heater with a resistance heated tube furnace due to the inability of the former unit to heat sections 1/16" and thinner satisfactorily under dynamic conditions was discussed in Interim Report No. XXII. It was also stated that heating trials would be conducted to evaluate methods to increase the heating efficienty of the induction unit.

During this quarter, a series of seven heating trials (shown in Table 1) were attempted to improve the heating efficiency of the induction heating unit in terms of increased coil turns and by insertion in parallel of a bank of ten .01 uf capacitors into the high frequency circuit.

Indication of success is shown in the No. 2 trial (Table 1). At that time, two feet of the workpiece reached a temperature of 1350° F before failure at the junction box. This was considerably higher than the temperatures reached with the old (25-turn) coil.

Subsequent trials 3, 4 and 5 were interrupted by cable failures at the junction box and required repairs in each case. For non-technical reasons, the trial of the new coil was discontinued.

In trial No. 6 after cable repairs were finally completed for the fifth time, the cables held up. However, the trial was made with the old (25 turn) Lepel coil as the first step in trying out a recommendation made by Lepel (adding capacitors in parallel with the coil - see Figure 5A).

In trial No. 7, a group of capacitors 0.01 uf were connected in parallel with the coil in an attempt to improve the ampere-turn to work relationship.

During trial No. 7, the capacitor lead cables overheated. At this point, less capacitors should have been used in parallel with the coil. However, the trials were discontinued due to removal of the heating equipment.

The evaluation of the new coil and parallel capacitor approach proved successful. The workpiece temperature was increased (Trial No. 2) and higher currents were noted (Trial No. 7).

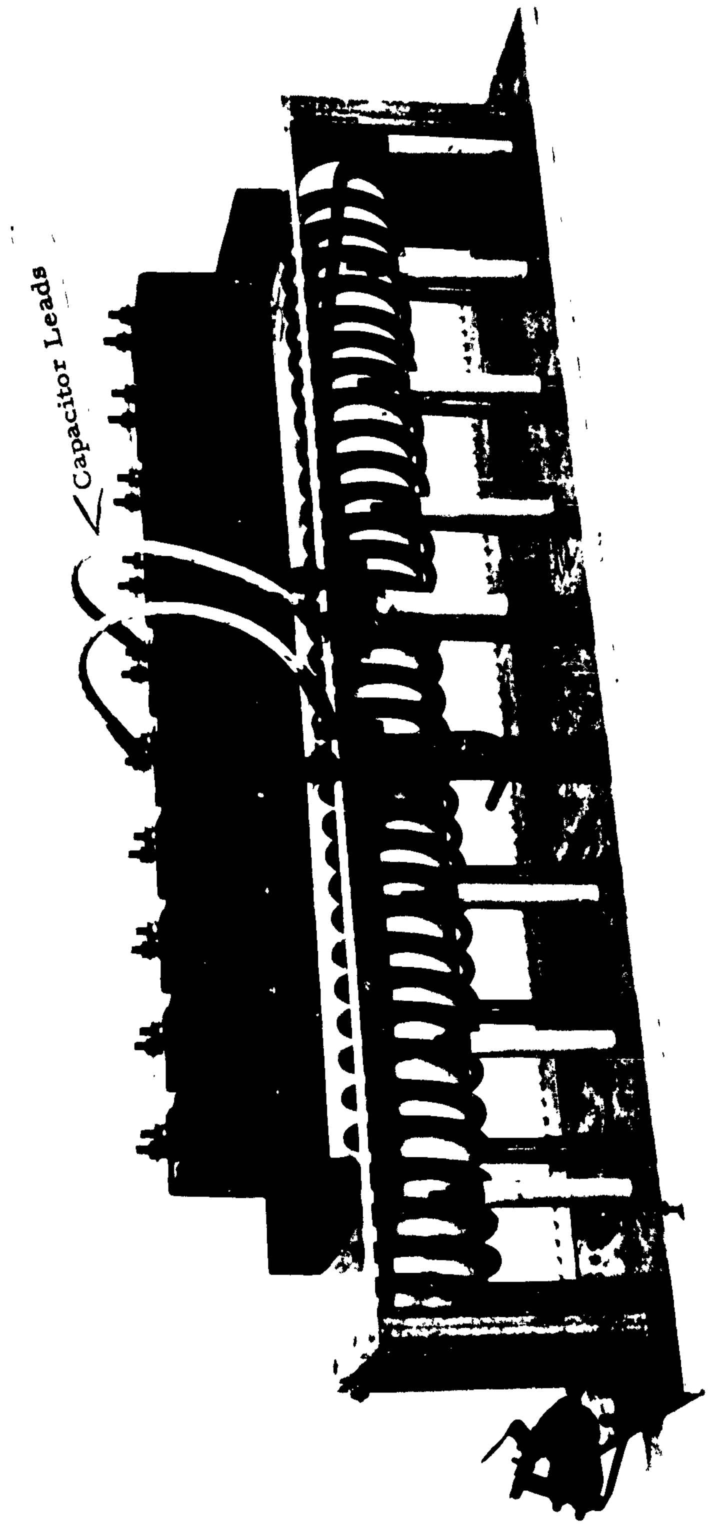
The conclusion is that a high frequency generator of higher rating and coaxial cables capable of better performance would be required for a production unit.

However, it is felt that a complete evaluation would be unnecessary in the current program since alternate radiant tube heating equipment is now available.

Induction Heater Trials

Trial No.	Date	Objective	Results
1	2/7/63	To test new 36-turn induction coil (previous coil had 25 turns) at max. power and 12'/min. feed.	No heating - water leak in coaxial cable (due to frozen lines) shorted circuit.
2	2/11/63	Repaired coaxial cable. Same as trial No. 1.	Temperature readings of the extrusion at the coil center indicated 1350° F. Arc failure at junction box occurred.
3	2/12/63	Same as above	Arcing of junction box.
4	2/18/63 & 2/19/63	Same as above	Freeze up of water lines and leaks due to extreme weather conditions.
5	2/21/63	Same as above	Arcing at junction box.
6	3/6/63	Repaired coaxial and junction box. Old coil installed at max. power to standardize unit.	Visible red heat in 18 seconds on a .065" thick "T" section static test.
7	3/6/63	Added capacitors in parallel with old coil.	Excess amperage for wire leads in capacitance branch. Insulation destroyed - no heating of extrusion. Difficulty in preventing overload tripping. Maximum applicable power approx. 50%.

TABLE 1



Ten .001 uf Capacitors Connected in Parallel to the New 36-Turn Induction Coil
FIGURE 5A

A radiant tube furnace, resistance heated, was engineered and built between September 15 and October 31, 1962 to fill the void left by the induction heater, as described in Interim Report XXII. A general view of this furnace in the draw bench trough is illustrated in Figure 6.

In summary, the central resistance heated tube chamber is Type 310 stainless steel, a nominal 3.00 in. ID x 0.098 in. W x 12-foot length. The tube is surrounded by 2800 series refractory MgO bricks and a carbon steel shell. One foot of the tube protrudes on each end to which the water cooled copper power clamps are attached. Two G. E. 1500 amperes continuous duty DC rectifiers are installed in parallel to supply 3000 amperes, 0-40 volts DC. The primary power source is three-phase 550 volts, approximately 200 KVA; the secondary is metered. The temperature is controlled by a controlling thermocouple.

The satisfactory temperature control in heating an extrusion longer than the furnace is depicted in Figure 7. The furnace, located about 6-8 inches away from the die stand, was set at 1325°F; the extrusion was then introduced with one end about 18-24 inches from the discharge port, heated 30 seconds, pushed through the die, and drawn at 12 fpm. In this curve the temperature varied only from about 870°F minimum to about 930°F maximum; one instantaneous peak of 1010°F was recorded. The power is generally on for 10-15 seconds (10-12V, 2500 A) and then off for 60-90 seconds. The calibration curve of the Pyrotel head used to measure draw temperatures is illustrated in Figure 8.

Minor, but objectionable arcing has occurred sporadically when the thin edged extrusions are in contact with the extremities of the tube furnace. The severity and frequency of these areas of metal spark erosion are depicted in Figure 9. Not many failures through these notches have been observed upon drawing. Initially, to circumvent this arcing, rings of Fiberfrax were inserted on both of the ends and the middle of the tube furnace to keep the extrusion from contacting and arcing to the tube. More recently a more positive means of preventing arcing consisted of turning the furnace power off during the draw operation. This practice is feasible as the temperature losses during the short draw cycle are minor in the well insulated furnace. This practice is limited to extrusions about 12 feet in length.

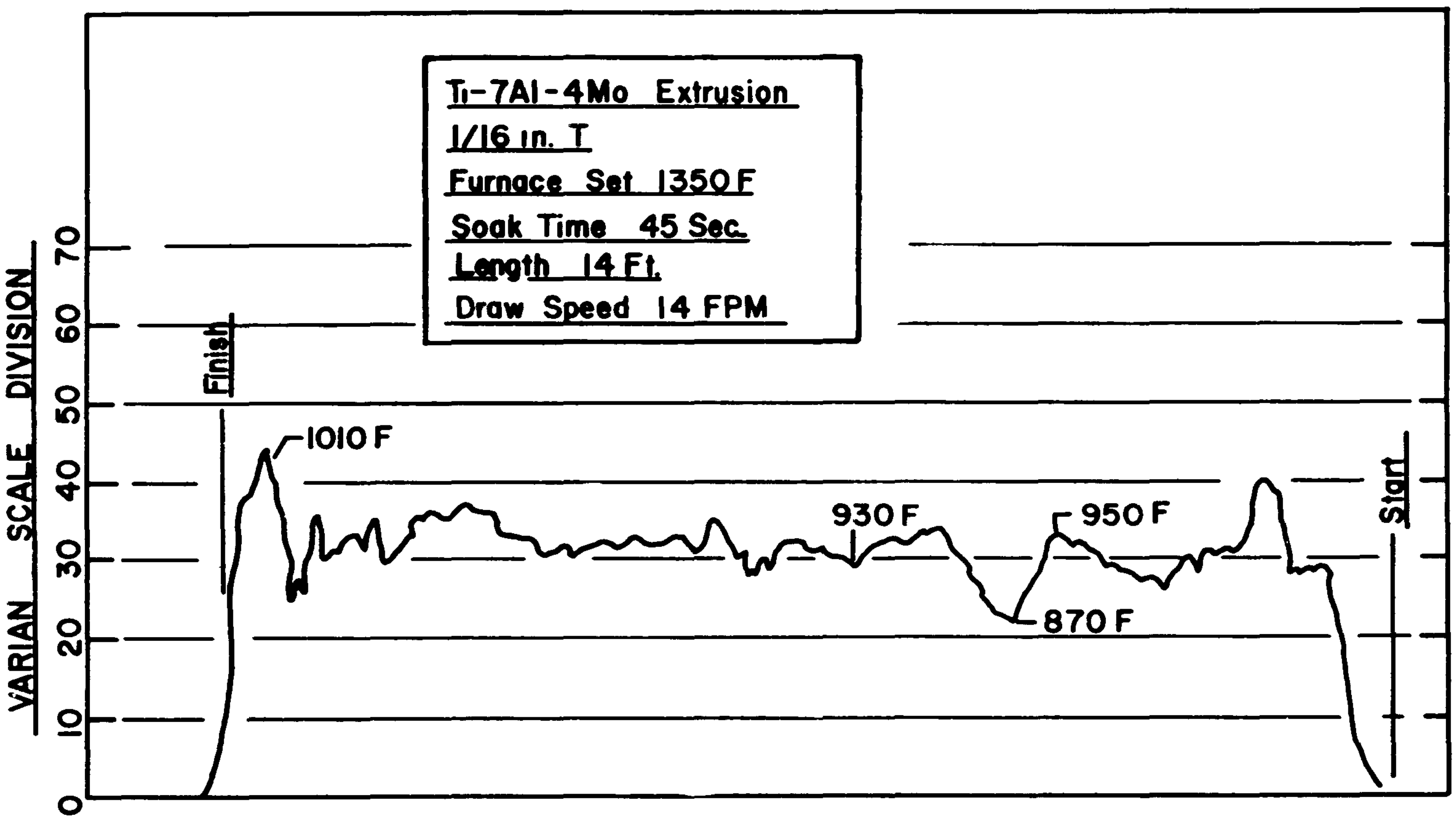
Gripper Head and Jaws

On the 30th of November, a change from the existing three cylinder gripper head and jaw design was accomplished. This head, used since the beginning of the program, was replaced by an 8 inch Hufford Universal Gripper. The Hufford jaw inserts are of the same design used in the Babcock and Wilcox stretcher straightener. The inserts manufactured by Hufford are 1020 carbon steel heat treated, carburized and chrome plated. It is no longer necessary to actuate the jaws with 500 psig as had been the case with the old head; the new jaws are actuated with 80-100 psig bottled nitrogen or air. Laboratory testing prior to delivery to Watervliet indicated that a 1-1/2 inch x 1-1/2 inch x 0.120 inch thick "T" sustained a 43,330 lb. load (120 ksi) without slippage.

Subsequent warm drawing trials have justified the transition to the Hufford Universal Gripper heads - no slippage has been encountered under the most

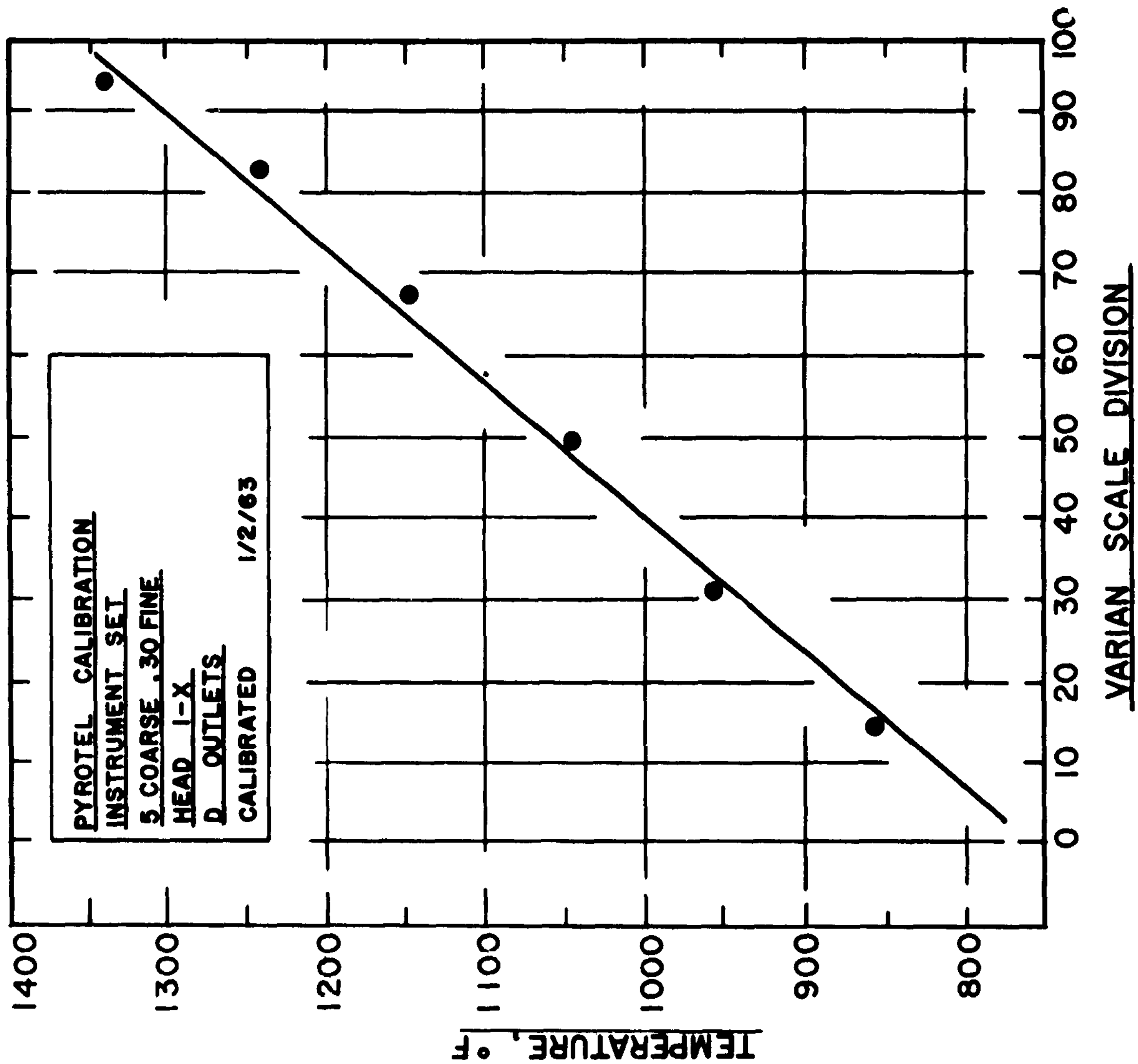
VIEW OF RESISTANCE HEATED TUBE MUFFLE FURNACE WHICH REPLACES THE 100 KW INDUCTION HEATER STANDING BY IN THE BACKGROUND (Arrow).

FIGURE 6

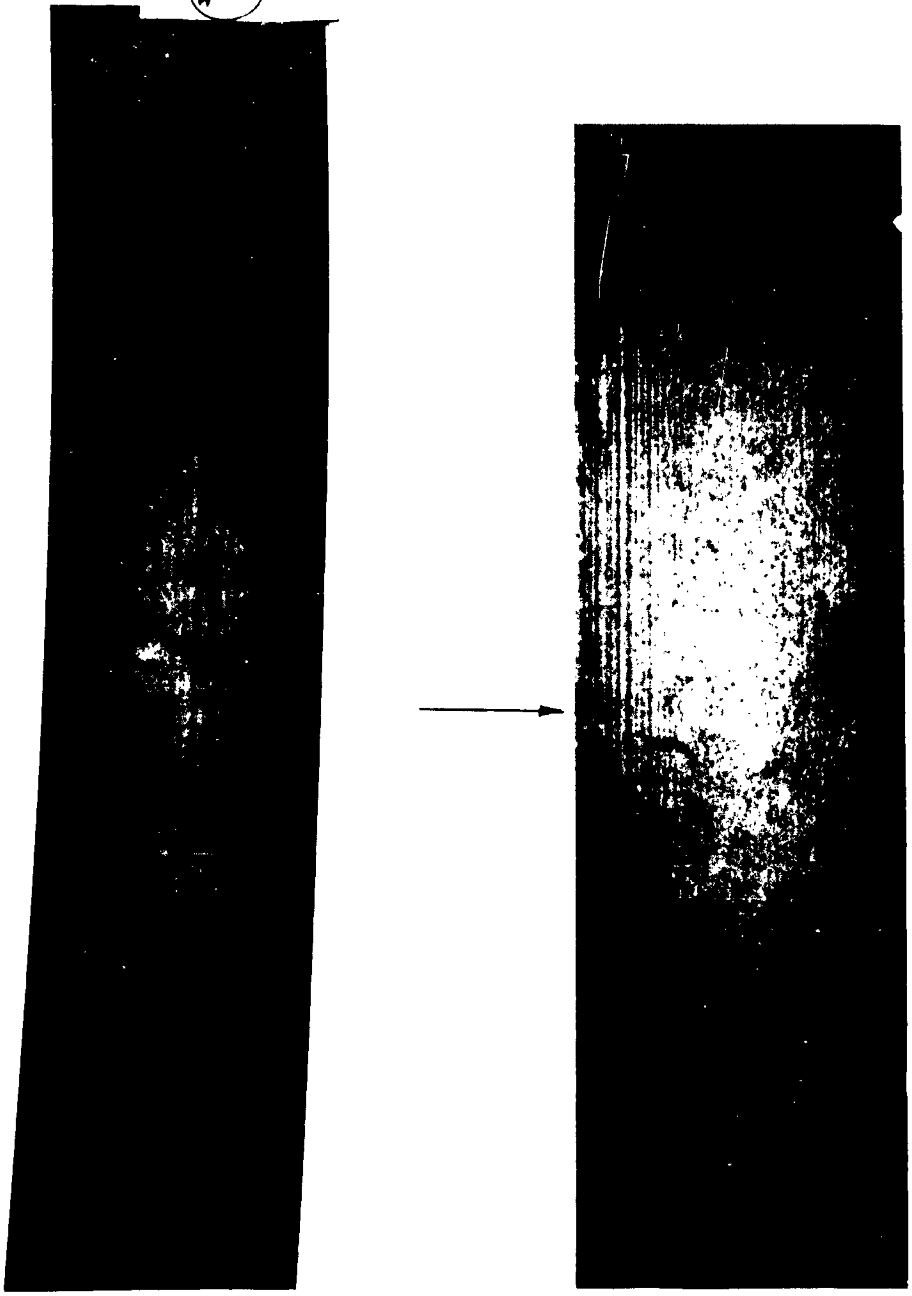


TEMPERATURE UNIFORMITY ALONG THE LENGTH OF A WARM DRAWN EXTRUSION, HEATED IN A RESISTANCE HEATED TUBE FURNACE, TEN FOOT LONG. TEMPERATURE MEASURED AT DIE ENTRANCE, 8 INCHES AWAY FROM THE EXIT END OF FURNACE.

FIGURE 7



PYROTEL HEAD CALIBRATION CHART.
FIGURE 8



1X 1X

VIEWS OF A NOMINAL 1/16in T EXTRUSION OF Ti-6Al-4V (No. 236) WARM DRAWN THROUGH THE 0.058in PASS; ILLUSTRATION OF ARCING ON THE EXTRUSION EXTREMITIES (Arrow).

FIGURE 9

adverse conditions. A view of the Hufford head in place on the trolley is shown in Figure 10.

Straightening

In-process straightening is still being conducted on the 7500-ampere AC resistance heater. It was found necessary to blanket these long, thin extrusions with asbestos or the Fiberfrax liners, otherwise it was impossible to impart sufficient heat into the sections for stretcher straightening; the radiation losses were too high and sufficient amperage could not be introduced without this protective cover. Detwisting is being conducted manually between the fixed ends.

To utilize the resistance heater as a stretcher straightener, a function it was never designed to perform, involves two drawbacks.

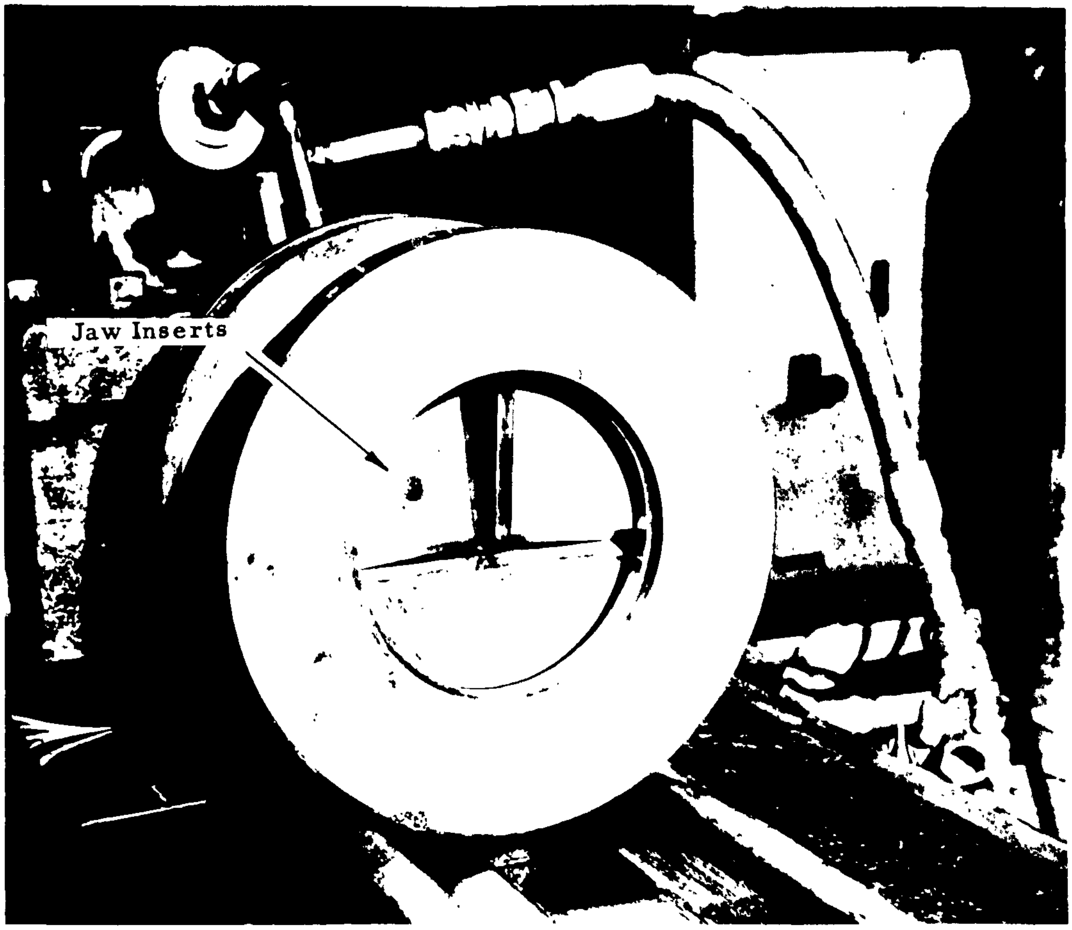
1. Approximately 18-24 inches must be removed from each end after each straightening effort; these are the unstraightened ends between the copper bus and the ratchet gear, gripper mechanism. This entails severe material attrition, particularly in extrusions requiring four or five draw passes. For example, a starting 20-foot length would be reduced to a finished 4-8 ft. length.

2. It is necessary to preheat to temperatures of about 1400/1500°F to stretcher straighten. This is to give assurance that the one horsepower motor can perform the stretching. The ensuing scaling and necessity for conditioning of the oxidized surface in a sodium hydride bath has exposed all extrusions to the danger of hydrogen embrittlement. Oxidizing descaling baths such as Virgo or Kolene are not available.

Fortunately, the in-process straightening problem has been solved in terms of conducting the remaining portion of the warm draw program at the newly installed TMCA warm drawing and stretch straightening facilities.

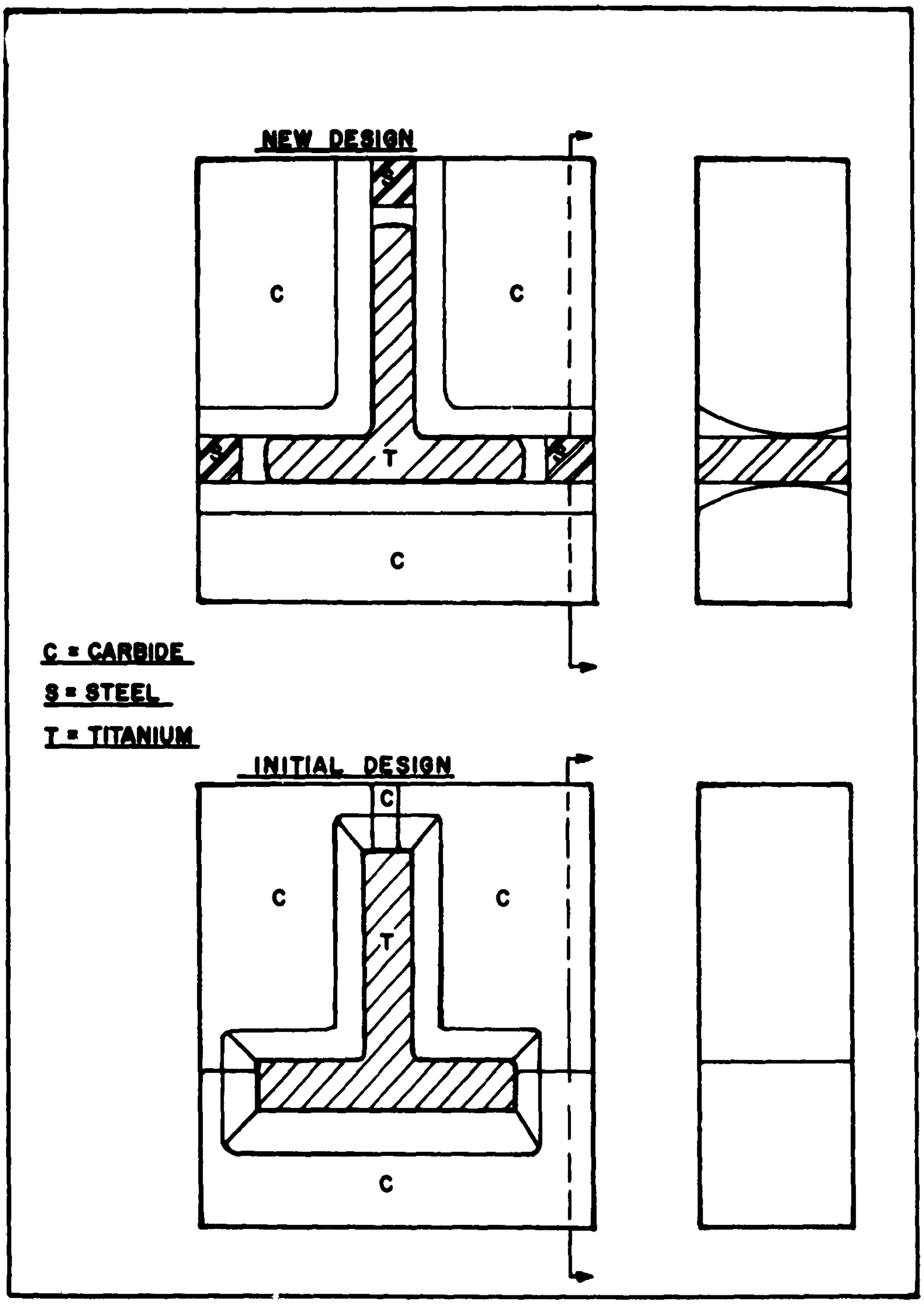
Draw Dies

The presence of heat checking on the upper right and left hand die blocks necessitated procurement of replacement components. These were delivered in November, 1962. Later in December, a change in draw die design was necessitated by difficulties in working the edges of the extrusion as well as the flat faces. Indications were that if the dies would be revamped to insure unrestricted movement of the edges during the draw, the drawing of the flat faces could proceed without the "Chevron" or buckling defect frequently encountered. One set of blocks (upper right and left hand and bottom blocks) was ground by AmCarb into the configuration shown schematically in Figure 11. The complicated 0.010" recesses to contour the edges of the extrusion in drawing have been eliminated. Dimensional control is accomplished by altering the size of the three steel shims; the bottom block was reduced in width to that of the narrowest flange dimension to which one would draw. It would be possible to insure end working in a final pass by introducing carbide end blocks but no such provisions have been made in this die set.



A VIEW OF THE 8in HUFFORD UNIVERSAL GRIPPER HEAD IN PLACE ON THE TROLLEY.

FIGURE 10



SCHEMATIC DRAWING ILLUSTRATING TYPICAL PREVIOUS DIE DESIGN AND THE MODIFIED DESIGN PERMITTING UNRESTRAINED, EDGE METAL FLOW.

FIGURE 11

Warm Drawing Trials and Auxiliary Processing

PHASE I

Objectives

The general objectives of Phase I were to develop drawing techniques for sizing as-extruded and straightened "T" shapes of Ti-7Al-4Mo having a nominal starting thickness of 0. 125".

Results

Ten lengths previously drawn to a nominal 0. 100" thickness were shipped to Babcock and Wilcox for stretcher straightening prior to heat treatment. On January 9, 1963, these extruded and drawn lengths were stretcher straightened and then gag straightened to remove the camber. These extrusions were vacuum annealed and heat treated at TMCA, Toronto, Ohio. A heat treatment of 1750°F (5 min) WQ + 1150°F (4 hrs)AC was applied after an initial vacuum anneal of 1350°F (2 hrs). The extrusions are presently at Babcock and Wilcox for final straightening and will be shipped back to TMCA for evaluation by TMCA and Republic Aviation personnel.

PHASES II AND III

Objectives

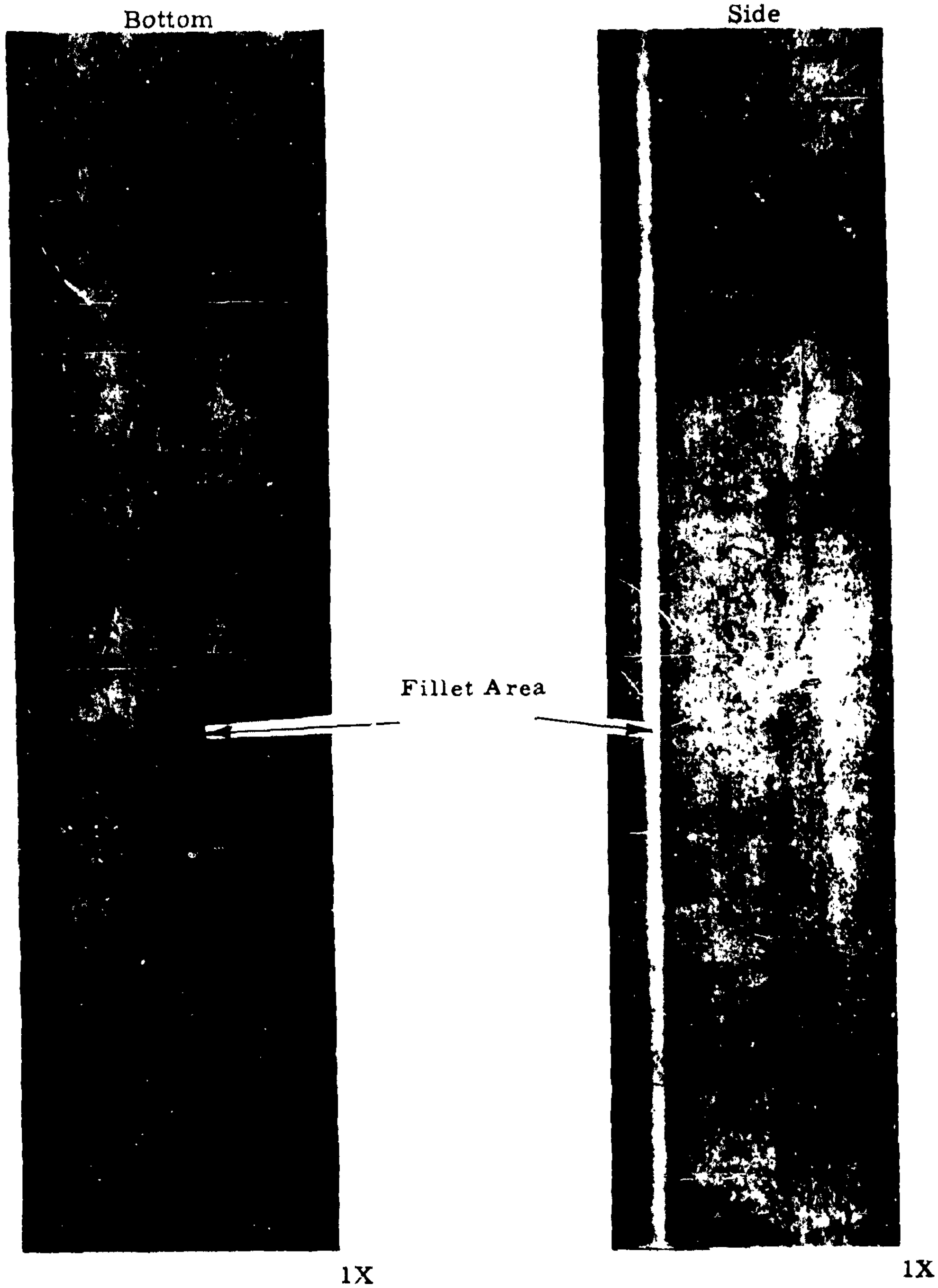
Modification of Phases II and III resulted in development of drawing techniques to produce warm drawn extrusions to 0. 065" thicknesses from either 1/8" or 3/32" thick starting extrusions.

Results

The four short lengths successfully warm drawn to 0. 065" nominal thickness were stretcher straightened and the sweep removed by gag straightening on Babcock and Wilcox facilities, January 9, 1963. The short lengths, all less than six feet, are attributed to the high losses in utilizing the available Allegheny Ludlum Steel Corporation stretcher straightener described previously.

These extrusions were vacuum annealed and heat treated at TMCA, Toronto, Ohio. The hydrogen level was reduced from 4000 ppm to approximately 50 ppm after a 1325°F (2 hr) vacuum anneal. These extrusions were heat treated at 1750°F (5 min) WQ + 1150°F (4 hrs) AC and will be evaluated to determine their mechanical properties.

In portions of these extrusions (near the fillets) wherein reductions of 25/30% of thickness were achieved, marked surface improvement is noted. However, at the thin extremities where significantly lesser reductions were achieved as the starting extrusions were tapered, little surface improvement was realized. Typical views of Phase III extrusions warm drawn to 0. 063" are presented in Figure 12.



TYPICAL SURFACES OF A 3/32in NOMINAL T EXTRUSION OF Ti-7Al-4Mo (No. 226) WARM DRAWN TO 1/16in. GREATER DEGREE OF SURFACE REFINEMENT IN FILLET AREA DUE TO HEAVIER WORKING. THIS CAN BE SEEN MORE CLEARLY IN FIGURE 18.

FIGURE 12

PHASE IV

Objectives

The objective of this Phase IV is the development of drawing procedures to produce 0.040" section shapes from extrusions having an initial nominal thickness of 0.063". Three alloy grades: Ti-7Al-4Mo, Ti-6Al-4V and Ti-4Al-3Mo-1V are included.

Results

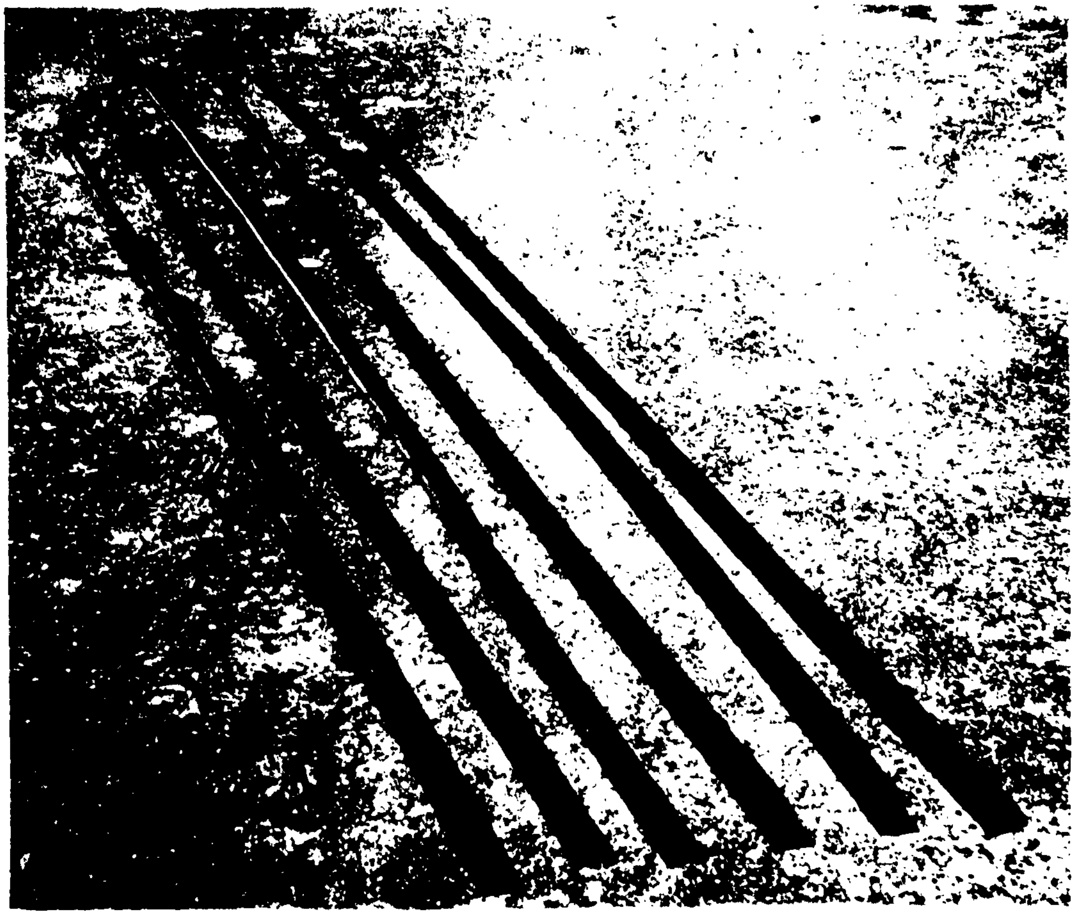
Typical views of the incoming Phase IV extrusions in the extruded and straightened condition are presented in Figures 13 and 14. The straightness was generally adequate to insert the extrusions into the 3" ID resistance heated tube furnace.

During the period from November 10 to 19, 1962, the infra-red radiation pyrometer Pyrotel head was recalibrated for use in conjunction with the electric resistance heated tube furnace and the drawing trials were resumed. Figure 8 shows the calibration curve. Throughout these trials, the lubricant system was as follows: Granodraw T subcoat, one coat of Alpha-Molykote 196X, and then an overcoat of Fiske 604 at the time of draw.

As stated in Interim Report XXII, eleven 1/16" as-extruded and straightened tee shaped sections were sized through the .065" pass. The newly installed resistance heated tube furnace was set at 1360°F (9V and 1250A for each of two rectifiers), the extrusion held for five seconds, and subsequently drawn at 12fpm through a preheated die 915°F. Between draws, the extrusions were resistance heated to the 1300/1400°F range, stretcher straightened and cleaned sequentially in sodium hydride, sulfuric acid, and nitric hydrofluoric acid baths. The extrusions were then reconversion coated and chemically repointed as necessary.

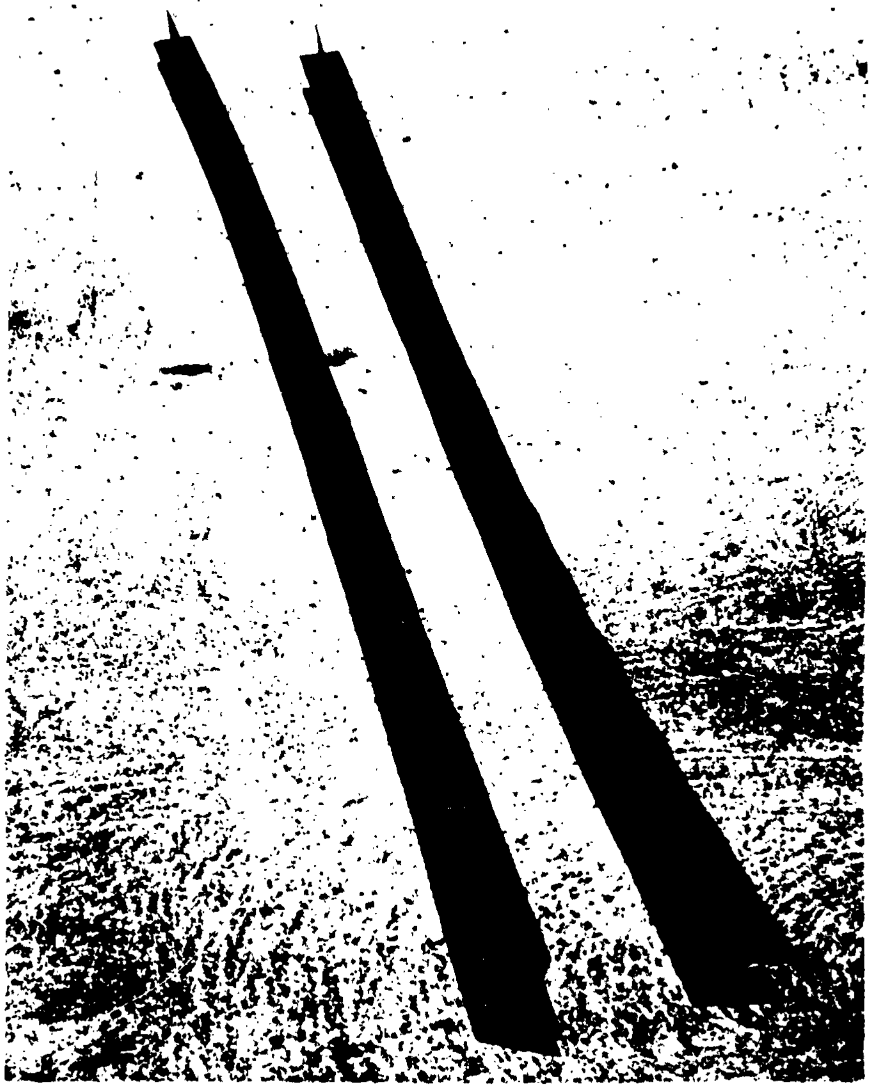
Four tee sections (Nos. 228, 232, 233 and 243) which were considerably oversized on the flange width and stem height were drawn through the 0.090, 0.082 and 0.072 in. dies to reduce the edges only. Extrusion No. 233 (Ti-7Al-4Mo) drawn through the .065" die experienced top edge stripping of the stem. The typical chevron defect due to non-uniform deformation and edge restraint is shown in Figure 15.

Measurements of these and other .058" (see Figure 16) drawn tee shaped cross sections revealed a .010" per pass growth across the horizontal and vertical legs. At the conclusion of this trial period, it became apparent that tearing as shown in Figure 15 will ensue if the extremities and the cross section reduction of the flat faces were worked simultaneously. The condition occurred particularly in thin sections where buckling by column failure resulted in the chevron defects. One set of draw dies were reworked to extend the vertical stem and horizontal flange orifice to permit unrestrained lateral flow while working the flat faces. A three-week delay in drawing was necessary to allow for the die modification.



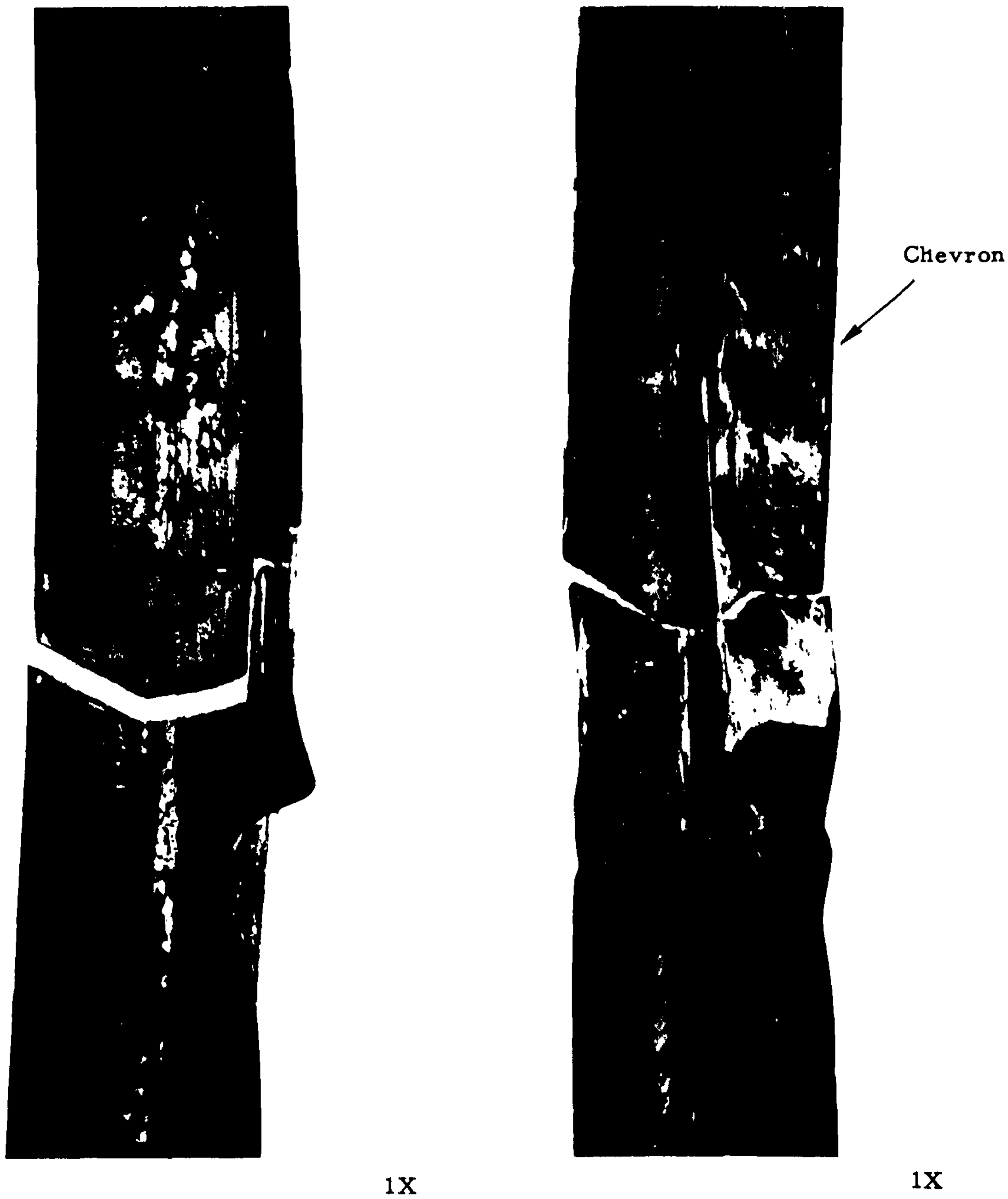
PHOTOGRAPH SHOWING THE STRAIGHTNESS OF MOST OF THE INCOMING PHASE IV EXTRUSIONS.
(1/16 inch Cross Section Thickness).

FIGURE 13



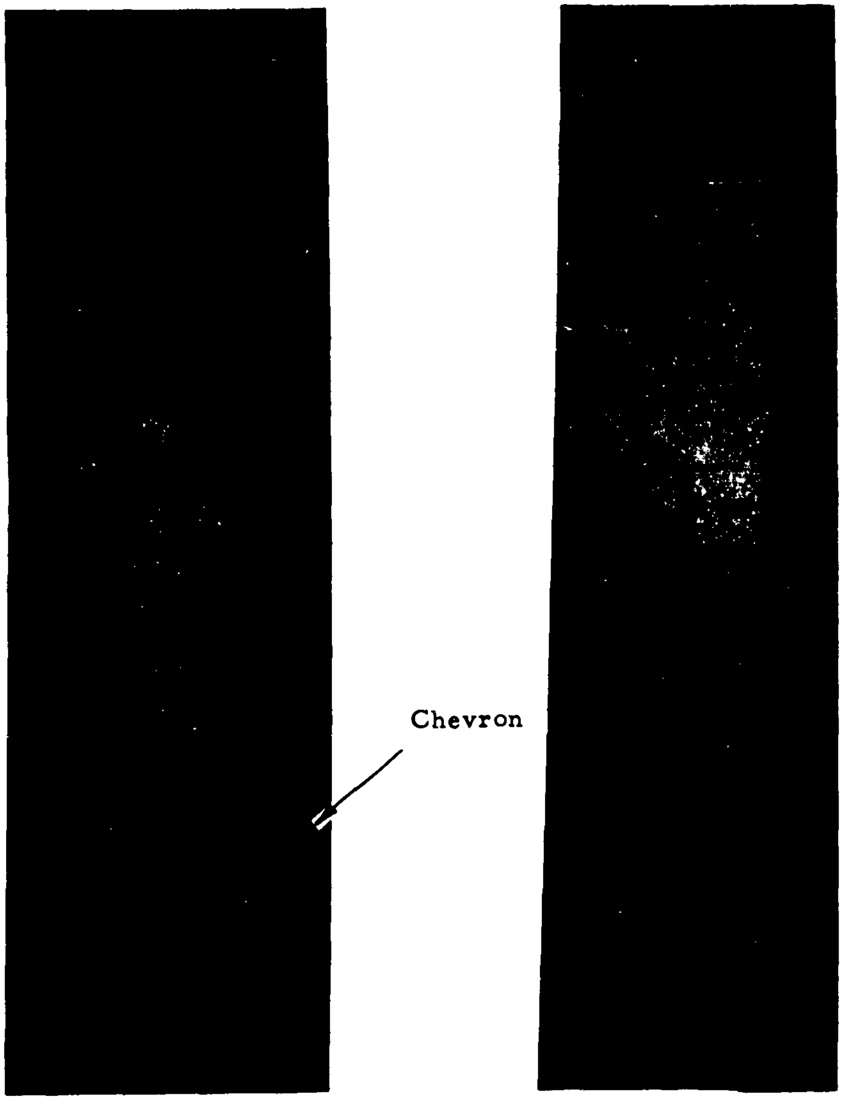
AN ILLUSTRATION OF THE BOW, TWIST AND WAVINESS ENCOUNTERED IN SOME OF THE INCOMING PHASE IV EXTRUSIONS.

FIGURE 14



BUCKLING AND RESULTANT CHEVRON DEFECTS IN A NOMINAL 1/16in T EXTRUSION OF Ti-7Al-4Mo; DEFECT DUE TO NON-UNIFORM WORKING OF BASE, AS NOTED.

FIGURE 15



1X 1X

VIEWS OF A NOMINAL 1/16in T EXTRUSION OF Ti-6Al-4V (No. 235) DRAWN THROUGH THE 0.052in DIE. MILD CHEVRON DEFECT ON EXTREME BACK END.

FIGURE 16

During this quarter, drawing trials were resumed, utilizing the revamped draw dies. Two lengths of Ti-7Al-4Mo and two lengths of Ti-4Al-3Mo-1V were drawn to the finished size of 0.043". Exceedingly short length tees resulted due to excessive end losses in stretcher straightening. Indications also were that all extrusions were of an exceedingly high hydrogen level as they all exhibited some degree of embrittlement. This is attributed to the use of the only available hot salt (sodium hydride) descaling bath at the mill. The exceptionally high hydrogen contents are indicated below. Initially, the incoming hydrogen levels were all below 125 ppm.

A - Starting Level (as received)

Alloy	H_2 ppm	O_2 %
Ti-6Al-4V	83	0.145
Ti-4Al-3Mo-1V	59	0.092
Ti-7Al-4Mo	88	0.110

B - In-Process Level (Warm Drawn)*

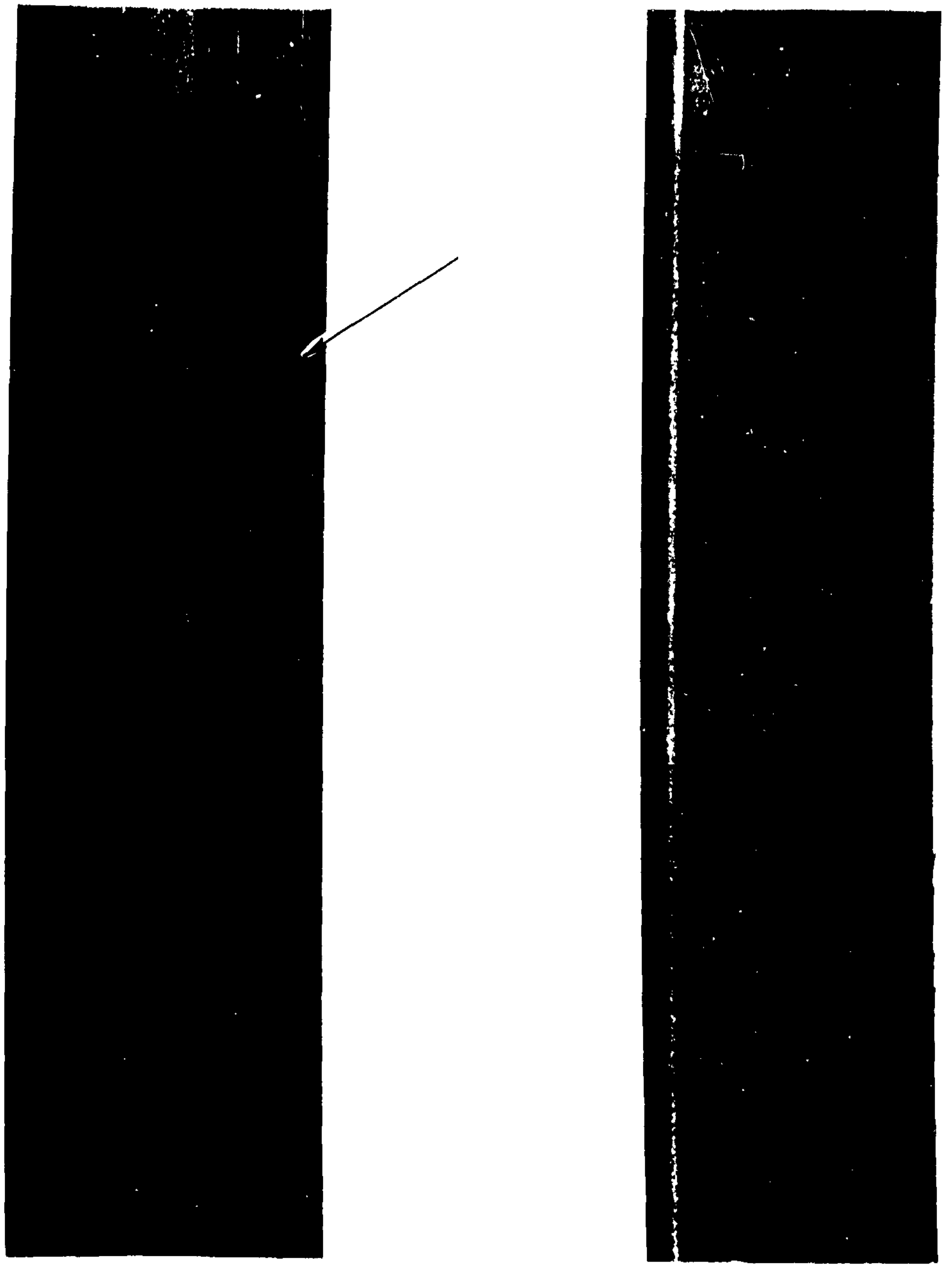
Ti-7Al-4Mo	1060	-
Ti-6Al-4V	2062	-
Ti-4Al-3Mo-1V	690	-

* 2-3 Descale Cycles

In view of the severe loss of material by in-process stretch straightening, it was decided to proceed with only two pieces of each grade to draw to the finished size. Any in-process straightening would be conducted on the Babcock and Wilcox facilities.

A view of a Ti-7Al-4Mo section reduced by drawing to 0.048" is shown in Figure 17; longitudinal striations have not been removed at this stage. The Ti-4Al-3Mo-1V extrusion warm drawn to 0.043" is shown in Figure 18. Poor quality is due to the lack of ironing and also failure to condition any scale formation from hot stretcher straightening prior to acid pickling. The descaling practice used was: immerse in sodium hydride, rinse, sulfuric acid die, rinse, nitric-hydrofluoric acid, rinse.

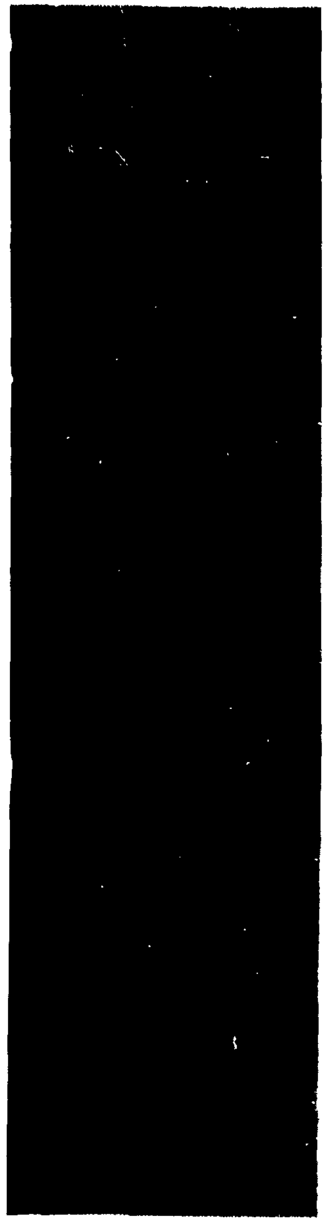
The borrowed set of Hufford jaws had to be returned to their owner and the initially designed jaws had to be employed. In an effort to draw the two pieces of each grade, the gripper head consistently slipped prohibiting any drawing and, therefore, work was called to a halt pending TMCA's decision to continue this program at the newly installed warm drawing facilities. This decision was affirmative and presently TMCA is in the process of tooling up to continue the warm draw program at their Toronto, Ohio plant.



1X 1X

VIEWS OF A NOMINAL 1/16in T EXTRUSION OF Ti-7Al-4Mo (No. 232) DRAWN THROUGH THE 0.048in DIE. LONGITUDINAL STRIATIONS ARE INDICATED BY ARROW.

FIGURE 17



1X

VIEW OF A NOMINAL 1/16in T EXTRUSION OF Ti-4Al-3Mo-1V (No. 242) FINISH DRAWN THROUGH THE 0.043in DIE.

FIGURE 18

Tensile Property Studies

The as-received mechanical properties and the heat treat response of incoming Phase IV extrusions was ascertained by means of laboratory studies. These results are summarized in Table 2. Also included are some 1000°F tensile tests to establish the relative ease of drawing at this temperature for the various grades. Upon examination of the results, it is evident that Ti-7Al-4Mo offers the greatest resistance to flow and Ti-6Al-4V the least.

The relatively poor heat treat response of Ti-4Al-3Mo-1V can be attributed to microstructural effects or a failure to achieve the indicated heat treatment. It has also been observed in weldments in this grade. This is being rechecked in further heat treat studies.

Table 3 reveals the properties of nominal 3/32" "T" shapes of Ti-7Al-4Mo warm drawn to 1/16". The properties are obviously not much different from those of incoming Phase IV Ti-7Al-4Mo extrusions similarly heat treated, but slight improvements in heat treated ductility are indicated.

Microstructural Examinations

Incoming Phase IV material was examined metallographically to establish a basis for comparison to material warm drawn to the finished sizes. Figures 19 and 20 reveal as-extruded and heat treated microstructures. All alloys reflect extrusion in the beta field.

A minor structural refinement is noted in the primary alpha particle size of the extrusions drawn to 1/16" from 3/32" when a comparison is made to an as-extruded 1/16" section (see Figures 21 and 22).

TENSILE PROPERTIES* OF INCOMING PHASE IV EXTRUSIONS

C- Ti-4Al-3Mo-1V - 1/16in T (No. 243)

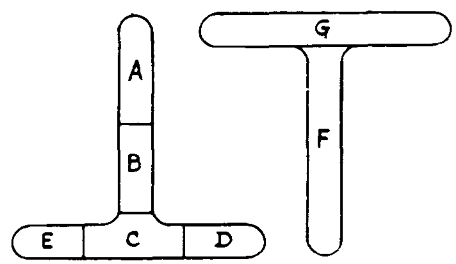
Location	Direction	Condition		UTS Ksi	YS(0.2%) Ksi	EL(1/2-1") %
A	L	Extruded & Straightened		147.2	135.5	12.0
B	L	" "		138.9	126.0	15.0
C	L	" "		135.8	122.3	12.5
D	L	" "	1000F	96.2	78.6	22.5
G	T	" "		135.5	113.9	BOGL
A	L	1250F(2hrs)AC		152.8	141.0	10.0
B	L	" "		142.6	129.8	13.5
C	L	" "		137.3	121.7	13.5
D	L	" "	1000F	94.3	80.9	16.0
G	T	" "		137.4	113.3	4.5

D - Ti-7Al-4Mo - 1/16in T (No. 230)

Location	Direction	Condition		UTS Ksi	YS(0.2%) Ksi	EL(1/2-1") %
A	L	1450F(1/2hr)FC 100F 1hr to 1000F AC		177.4	157.8	14.0
B	L	" " "		168.6	151.9	10.0
C	L	" " "		165.9	147.6	11.5
D	L	" " "	1000F	115.2	93.8	12.5
A	L	1750F(5min)WQ + 1150F(4hrs)AC		196.7	175.0	7.0
B	L	" "		193.6	168.7	6.0
C	L	" "		185.8	171.5	5.0
D	L	" "		202.5	176.6	5.0

* Sheet tensile specimens with 1 inch gage length for L samples and 1/2 inch gage length for T samples. Surfaces machined about 0.005/0.010in per side.

TABLE 2



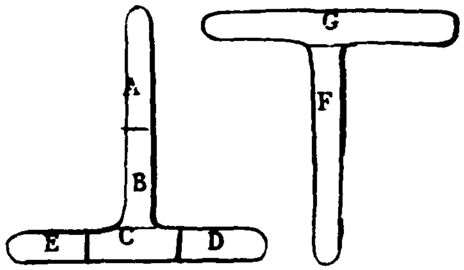
TENSILE PROPERTIES* OF INCOMING PHASE IV EXTRUSIONS

B - Ti-6Al-4V - 1/16in (No. 226)

A	L	Extruded & Straightened		155.8	141.4	15.0
B	L	" "		152.2	135.7	17.0
C	L	" "		148.7	131.8	15.0
D	L	" "	1000F	90.8	72.8	22.5
F	L	" "		152.0	129.2	10.0
A	L	1725F(5min)WQ+1000F(4hrs)AC		178.4	161.6	10.0
B	L	" "		174.1	157.2	7.0 Q
C	L	" "		173.0	153.9	10.0
D	L	" "		178.6	162.3	9.0
F	L	" "		179.6	158.1	7.5
A	L	1300F(2hrs)AC		152.5	138.0	13.0
B	L	" "		152.3	135.9	14.0
C	L	" "		147.8	132.9	12.0
D	L	" "	1000F	85.2	66.1	19.0
F	T	" "		143.8	125.4	9.0
G	T	" "		146.1	126.2	10.0
A	L	1675F(5min)WQ+1000F(4hrs)AC		177.5	156.1	12.0
B	L	" "		171.9	154.1	8.5
C	L	" "		169.1	151.1	9.0
D	L	" "		174.1	155.3	12.0

TABLE 2 (Continued)

TYPICAL TENSILE PROPERTIES * OF A Ti-7Al-4Mo
EXTRUSION 3/32in T (NO. 223) WARM DRAWN TO 1/16in



Location	Direction	Condition	UTS Ksi	YS(0.2%) Ksi	EL(1/2-1") %
A	L	As Warm Drawn	184.6	164.8	9.0
E	L	" " "	188.3	168.0	9.0
B	L	1450F(1/2hr)SC 100F 1hr to 1000F AC	170.8	152.4	14.0
C	L	" " "	172.8	157.6	10.0
D	L	" " "	183.5	164.7	14.0
F	T	" " "	162.1	140.4	12.0
G	T	" " "	170.7	148.6	7.0 Q
A	L	1750F(5min)WQ + 1100F(4hrs)AC	219.4	190.7	3.5
D	L	" + 1150F "	202.3	182.7	4.0
E	L	" + 1200F "	194.4	175.6	6.0
B	L	" + 1150F "	193.2	169.8	5.0
C	L	" " "	193.2	170.3	8.0
F	L	" " "	197.4	168.2	4.0 Q
G	L	" " "	205.5	173.4	7.0 Q

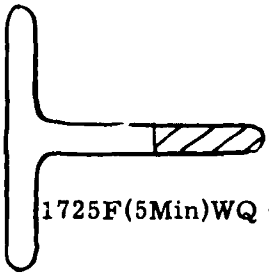
* Sheet type tensile specimens with 1 inch gage length in the L direction and 1/2 inch for the T direction; specimens machined 0.005/0.010in per side.

TABLE 3

As Extruded & Straightened

Longitudinal

UTS, Ksi 155.8
YS(0.2%), Ksi 141.4
El(1 in), % 15.0



1725F(5Min)WQ + 1000F(4Hrs)AC

UTS, Ksi 178.4
YS(0.2%), Ksi 161.6
El(1 in), % 10.0

TRANSVERSE MICROSTRUCTURES OF A NOMINAL 1/16in Ti-6Al-4V (No. 226), AS EXTRUDED AND STRAIGHTENED AND ALSO IN THE HEAT TREATED CONDITION.

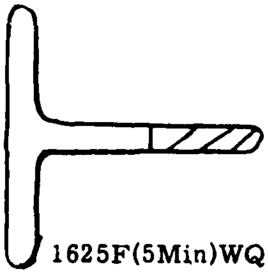
FIGURE 19

As Extruded & Straightened

Longitudinal

UTS, Ksi	147.2
YS(0.2%), Ksi	135.5
El(1 in), %	12.0

500X



1625F(5Min)WQ + 925F(12Hrs)AC

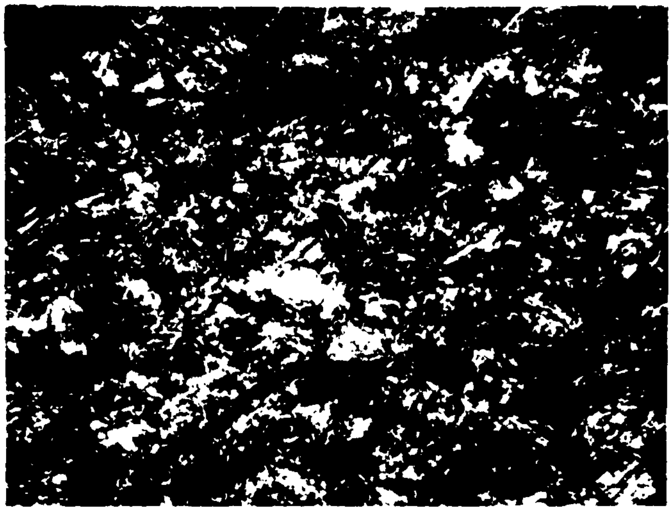
UTS, Ksi	167.4
YS(0.2%), Ksi	136.2
El(1 in), %	7.0

500X

TRANSVERSE MICROSTRUCTURES OF A NOMINAL 1/16in T EXTRUSION OF Ti-4Al-3Mo-1V (No. 243) AS EXTRUDED AND STRAIGHTENED AND ALSO AS HEAT TREATED.

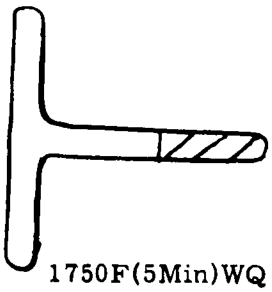
FIGURE 20

1450F(1/2Hr)FC to 1000F, AC

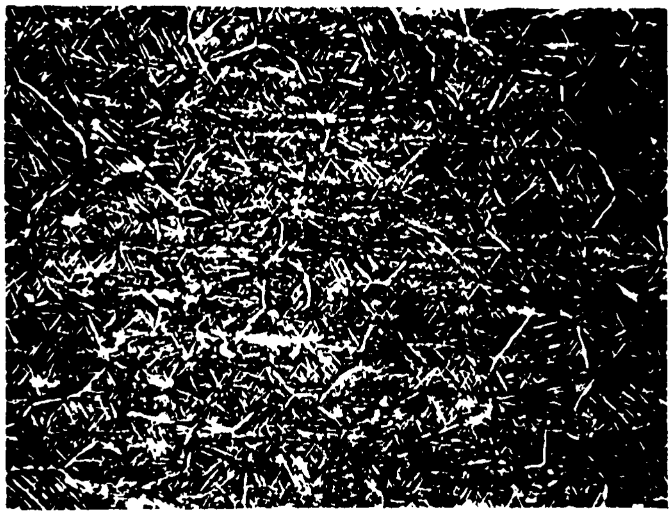


UTS, Ksi	177.0
YS(0.2%), Ksi	157.8
El(1 in), %	14.0

500X



1750F(5Min)WQ + 1150F(4Hrs)AC



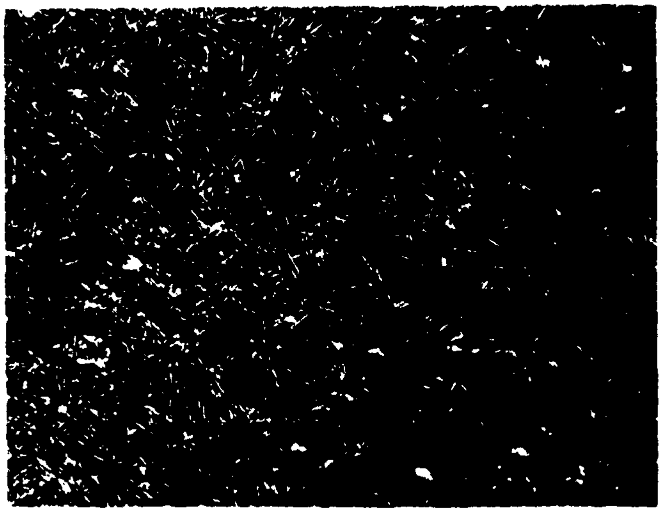
UTS, Ksi	196.7
YS(0.2%), Ksi	175.0
El(1 in), %	7.0

500X

TRANSVERSE MICROSTRUCTURES OF A NOMINAL 1/16in T OF Ti-7Al-4Mo (No. 230), ANNEALED AND ALSO IN THE HEAT TREATED STATE.

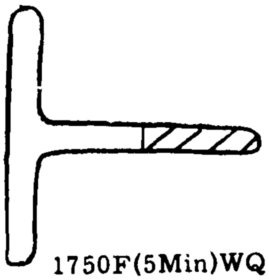
FIGURE 21

As Drawn to 0.065in

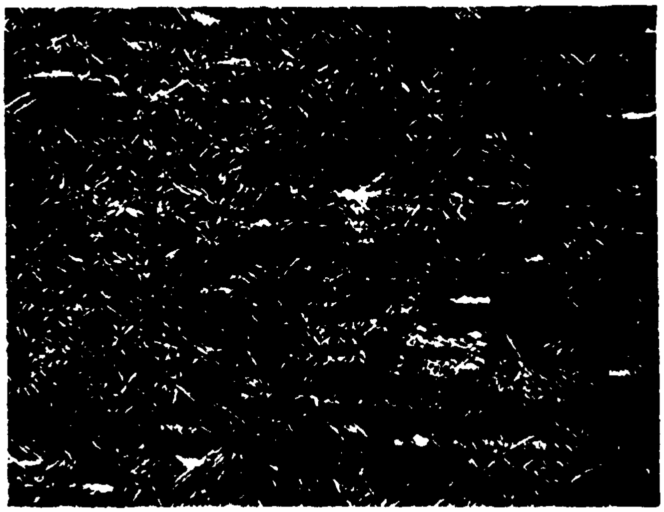


500X

UTS, Ksi	184.6
YS(0.2%), Ksi	164.8
El(1 in), %	9.0



1750F(5Min)WQ + 1150F(4Hrs)AC



500X

UTS, Ksi	202.3
YS(0.2%), Ksi	182.7
El(1 in), %	4.0

TRANSVERSE MICROSTRUCTURES OF A NOMINAL 3/32in T OF Ti-7Al-4Mo (No. 223), AS WARM DRAWN TO 1/16in AND ALSO IN THE HEAT TREATED CONDITION.

FIGURE 22

Conclusions

The use of the 100 KW Lepel induction heater was disbanded during this quarter, and a resistance heated (3000A, 0-50V) radiant tube furnace was engineered and placed into service. The 10 foot long furnace was readily capable of heating 1/16" thick and thinner extrusions uniformly to draw temperatures of 1000°F at the die entrance at draw speeds of 12/14 fpm without difficulty. The furnace was preset at about 1350°F.

The use of the Hufford Universal Gripper was adopted and provided a more positive means of gripping the extrusions during warm drawing.

During this quarter, basically all the incoming 1/16" nominal thickness extrusions were sized through the 1.975" x 1.730" x 0.065" die pass; three extrusions (Ti-7Al-4Mo) approximating a 3/32" thickness required sizing through the 0.090, 0.080 and 0.072" dies prior to the 0.065" set. All three grades Ti-6Al-4V, Ti-4Al-3Mo-1V and Ti-7Al-4Mo have been drawn without any particular difficulty. When reductions in the leg width and height were attempted along with web thickness reduction, the extrusions were failing in drawing due to material buckling and development of a "Chevron" defect with eventual tearing of a leg of the tee extrusion. Extrusions originally undersize on the leg width or height on a given die pass have invariably been drawn successfully; in these cases, measurements indicate an 0.005 to 0.015" lateral expansion of the leg extremities during the draw cycle.

Extending the orifice extremities of one existing die set permitted drawing without restraining of the edges. Two lengths of Ti-7Al-4Mo and two lengths of Ti-4Al-3Mo-1V were drawn through the required final pass of 0.043", indicating the feasibility of drawing titanium alloys to this thickness. Metal losses have been high mainly due to excess end waste in stretcher straightening.

A study of the heat treat response of the starting, nominal 1/16" extrusions has been completed.

CONCLUSIONS AND RECOMMENDATIONS

The specific conclusions for the technical work conducted during the reporting period have been presented at the end of each section. The most significant conclusions and recommendations of this work are repeated and summarized below:

Part V - B-70 Extrusion and Warm Drawing Program

The most significant conclusion of the extrusion program through Part IV has been the successful extrusion of 20-foot lengths of 1/16" cross section tee shapes in 7Al-4Mo, 6Al-4V and 4Al-3Mo-1V titanium alloys. Based upon the extrusion techniques developed through Part IV, an extrusion gram has been scheduled for the extrusion of 3/32" and 1/16" tee shapes the 6Al-4V titanium alloy for the XB70 aircraft to prove the feasibility for a production extrusion application. The extruded section will be warm drawn to a uniform .080 and .043" cross section thickness in accordance with the North American Aviation B-70 specifications.

Warm Drawing Program

1. Successful warm drawing of nominal 1/16" as-extruded tee shaped sections to a uniform .043" cross section has been accomplished in 7Al-4Mo, 6Al-4V and 4Al-3Mo-1V titanium alloys.

2. The feasibility of warm draw application has been substantiated. The problems of chevron defects and buckling of the stem and flange areas have been overcome by extending the orifice extremities of the tungsten carbide draw dies thereby permitting drawing without restraining of the tee edges.

3. The remainder of the warm drawing program including the Part V phase will be conducted at the newly installed warm drawing facilities of the Titanium Metals Corporation of America at Toronto, Ohio. Modification to the TMCA die housing in terms of enlarging the back-up block orifice and machining of a front plate and steel wedges to accommodate the original tungsten carbide draw dies used at Allegheny Ludlum Steel Corporation is currently being conducted.

PROGRAM FOR THE NEXT QUARTER

The Part V, B-70 shape extrusion schedule is tentatively set for the third week in April 1963 in which the initial effort shall include extruding seven 3/32" cross section tee shapes to be drawn to .080" (NAA 64E-15) and seven 1/16" cross section tee shapes to be drawn to .043" (NAA E64-12) in the 6Al-4V titanium alloy. Three extrusion pushes having two tee port openings per die will be extruded to demonstrate multi-hole extrusion capabilities.

The modification of the TMCA die housing in terms of enlarging the back-up block opening, machining a new die cover plate, and machining steel wedges and shim plates should be completed by April 12, 1963.

Draw work will be completed on Phase IV extrusions to further demonstrate the feasibility of drawing to 0.043" thick sections, which have already been demonstrated on several shorter lengths of Ti-7Al-4Mo and Ti-4Al-3Mo IV tee sections.

It is anticipated that this program will be brought to its conclusion during this quarter. Evaluation of the heat treated and straightened Phase I, II and IV extrusions will be completed and basic data on heat treated properties obtained.

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